AD-A071 285 MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN E--ETC F/G 13/10
THE EFFECTS OF INTERACTION FORCES BETWEEN SHIPS IN PROXIMITY ON--ETC(U)
JUN 78 R E CONRAD N00014-75-C-1006

UNCLASSIFIED NL

1 OF 2

AD
A071285

DATA SHEET

PHOTOGRAPH

THIS SHEET

II

LEVEL

1

INVENTORY

AD A071285

DDC ACCESSION NUMBER

The Effects of Interaction Forces Between Ships ----

DOCUMENT IDENTIFICATION

by Rielly Eames Conrad

Dtd June '78

DISTRIBUTION STATEMENT A

Approved for public release;

Distribution Unlimited

DISTRIBUTION STATEMENT

Accession For	
NTIS GRA&I	X
DDC TAB	
Unannounced	
Justification Per FL-88 (R77-2416)	
By (2nd request) on file	
Distribution/	
Availability Codes	
Dist.	Avail and/or special
A	23 cp

RE: Copyright Notice

DISTRIBUTION STAMP

DDC given permission to accession document

DDC

RECEIVED

JUL 17 1979

D

DATE ACCESSIONED

79 06 26 063

DATE RECEIVED IN DDC

PHOTOGRAPH THIS COPY

THE EFFECTS OF INTERACTION FORCES BETWEEN SHIPS IN PROXIMITY ON THE DESIGN OF RUDDER SIZE AND RATE

by

RIELLY EAMES CONRAD

B.E.S.M.E., Brigham Young University
M.E.M.E., Brigham Young University
(1971)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF

MASTER OF SCIENCE

IN NAVAL ARCHITECTURE AND MARINE ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June, 1978

Contract No N00014-75-C-1006

Signature of Author. . Rielly E Conrad . . . .
Department of Ocean Engineering, June, 1978

Accepted by. . . Martin A Abkowitz . . . .
Thesis Supervisor

Certified by . . . .
Chairman, Department Committee on Graduate Students

THE EFFECTS OF INTERACTION FORCES BETWEEN SHIPS IN PROXIMITY ON THE DESIGN OF RUDDER SIZE AND RATE

by

RIELLY EAMES CONRAD

Submitted to the Department of Ocean Engineering on April 14, 1978 in partial fulfillment of the requirements for the degree of Master of Science in Naval Architecture and Marine Engineering.

ABSTRACT

Rational design of rudder size and rate requires consideration of operational demands on the control of the ship caused by the presence of another ship or restricted waters. A mathematical model is developed from a velocity potential description for each ship, consisting of a distribution of sources for the ship in open ocean and horizontal and vertical dipole distributions to account for the other ship in proximity and shallow water, respectively. The Lagally theorem is used to calculate the interaction forces and moments, and ship trajectories are calculated using standard ship equations of motion in the lateral plane. Linear control theory is used to control the rudder and speed of the ship to approximately simulate the action of the helmsman. Comparisons of theoretical forces and moments with model test results showed good agreement except for underprediction of these in shallow water. The effects of increases in rudder size and rudder rate on underway replenishment operations are simulated. The results show that changes in rudder control sensitivities have much greater effects than changes in rudder size or rate on replenishment operations.

Thesis Supervisor: Martin A. Abkowitz

Title: Professor of Ocean Engineering

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

A rudder should be designed rationally to meet all the maneuvering demands of the ship that it steers. Traditionally, the rudder is designed to give a particular turning diameter. The rudder design is checked to assure that the ship is directionally stable by performing Dieudonne spiral tests and zig-zag tests. This procedure provides a rudder design that is adequate for open ocean maneuvers and course-keeping. When the ship is required to maneuver in a channel or harbor, to pass another ship, or to be involved in underway replenishment, the traditional method gives no direct assurance that the rudder design is adequate. These demanding maneuvers have resulted in some collisions and several near misses or periods when the ship is not in full control. Previous work in the area of predicting the interaction forces on ships in proximity (Reference 1) indicated that the helmsman or automatic heading control was required to be significantly more sensitive during these difficult maneuvers than during course-keeping. This thesis undertakes to demonstrate the influence of increased rudder size and rate on the performance of underway replenishment, which would indicate that simulation of this maneuver

should be part of the rudder design procedure.

The mathematical model development begins with the velocity potential function description, using sources and horizontal and vertical dipoles, which includes the effects of shallow water using an approach similar to that of Reference 1. The interaction forces and moments calculations are performed using the Lagally theorem following the method of Reference 1. The ship trajectory calculations use standard ship equations of motion in the lateral plane. The ship control calculations use linear control theory to control ship heading, relative separation and heading, ship speed, and relative speed and longitudinal separation. The mathematical model is compared with model test results to indicate the accuracy of the model. The mathematical model is used to show rudder design effects on replenishment operations for a Navy oiler and destroyer.

CHAPTER 2

MATHEMATICAL MODEL DEVELOPMENT

2.1 Velocity Potential Function Description

The interaction forces in this mathematical model are assumed to be pressure forces caused by the interaction of the potential flow fields of the two ships, as hypothesized by Havelock. A rigid free surface is assumed which leads to use of half of a double body to describe the ship. The body is assumed to be a slender body of revolution whose area and radius are based on the sectional area of the respective ship station. The velocity potential of a body moving at velocity U is:

$$\phi(x) = -U(x) + \int_{\text{bow}}^{\text{stern}} \frac{m(x)}{R}\, dx \qquad (1)$$

where R is the radial distance from the axis, and m(x) is the source strength. The boundary condition of zero radial velocity due to the sources leads to the following expression for the source strength:

$$m(x) = U\ R_b(x)/2\ \frac{dR_b(x)}{dx} \qquad (2)$$

where R(x) is the radius of the body, which is equal to the radius of a semicircle of area equal to the ship sectional area.

When two ships are near, the radial velocity due to the distribution of sources representing one ship upsets the boundary condition on the other ship. To restore the boundary condition, a distribution of dipoles (doublets) is sized to counter the induced cross flow of the sources. For a slender cylinder in cross flow, the dipole potential is:

$$\phi(x) = \int_{\text{bow}}^{\text{stern}} \frac{d(x)y}{R^3}\,dx \tag{3}$$

where d(x) is the dipole strength, y is the transverse distance sources, and R is the radial distance from the sources. The boundary condition of zero radial velocity due to the dipole and the respective induced source flow leads, according to Reference 2, to the following lateral dipole strength:

$$d_y(x) = q_y(x)/4 \ (1 + A_{22}) R_b{}^2(x) \tag{4}$$

where q_y is the induced cross flow velocity in the y direction and A_{22} is the non-dimensional lateral added mass of the body.

The effects of shallow water are taken into account by locating an image of each ship at a distance equal to the

depth of the water below the bottom of the water (see Figure 1). The presence of the image ship upsets the boundary condition in the vertical plane and by the same reasoning as above, requires a vertical distribution of dipoles of strength:

$$d_z(x) = q_z(x)/4 \ (1 + A_{33}) R_b^{\ 2}(x) \tag{5}$$

where q_z is the induced cross flow velocity in the z direction and A_{33} is the non-dimensional vertical added mass of the body.

The effects of lateral (sway) and rotational (yaw) motion of the ship cause the following contributions to the lateral dipole distributions:

$$d_{yv}(x) = v/4 \ (1 + A_{22}) R_b^{\ 2}(x) \tag{6}$$

$$d_{yr}(x) = r \ x/4 \ (1 + A_{22}) R_b^{\ 2}(x) \tag{7}$$

where v is the sway velocity (y-direction) and r is the yaw rate of the ship, and x is the distance along the length of the ship. Corresponding contributions to the vertical dipole distribution due to heave and pitch would have similar expressions. However, heave and pitch motions have

been neglected in the computer program, except that static sinkage and trim are calculated from the interaction and shallow water forces and moments in the vertical plane utilizing the hydrostatic properties of the hull of tons per inch immersion and moment to trim one inch.

The dipole distributions due to the second ship, the image ships for shallow water, and the ship's own motion all act to upset the boundary condition of zero radial velocity. If the strengths of the source and dipole distributions are again calculated based on the modified flow field, it is possible to converge to the boundary condition after several iterations. It was found in this and previous work (Reference 1) that two revisions of the strengths was a reasonable compromise between accurate convergence and computation speed.

The total velocity potential for each ship is:

$$\phi(x) = \int_{\text{bow}}^{\text{stern}} \frac{m(x)}{R}$$

$$+ \frac{y[d_y(x) + d_{yv}(x) + d_{yr}(x)] + [d_z(x)]z}{R^3}\, dx \quad (8)$$

where $R = (x^2 + y^2 + z^2)^{1/2}$ is the radial distance from a

location on one ship to a location on the other ship which is influenced by the potential. It is necessary to apply the transformation matrix for trim and yaw (Reference 3).

$$T(\theta,\psi) = \begin{vmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ -\sin\psi & \cos\psi & 0 \\ \sin\theta\cos\psi & \sin\theta\cos\psi & \cos\theta \end{vmatrix} \qquad (9)$$

to get the radial distance from the influenced ship I to ship K in the reference system of ship I (see Figure 1) as follows:

$$R_I = T_I \begin{vmatrix} x_{0I} \\ y_{0I} \\ z_{0I} \end{vmatrix} + \begin{vmatrix} x_I \\ 0 \\ 0 \end{vmatrix} - T_I \begin{vmatrix} x_{0K} \\ y_{0K} \\ z_{0K} \end{vmatrix} - T_I T_K^{-1} \begin{vmatrix} x_K \\ 0 \\ 0 \end{vmatrix} \qquad (10)$$

where T_I is defined for θ_I and ψ_I of ship I; x_o, y_o, z_o are fixed coordinates, and T_K^{-1} is the inverted transformation matrix for ship K. If the above R_I is defined as

$$R_I = \begin{vmatrix} x_I \\ y_I \\ z_I \end{vmatrix} \qquad (11)$$

where x_I represents all of the terms in the top line of Equation (10), etc., then R_K is defined as

$$R_K = T_K T_I^{-1} R_I = \begin{matrix} x_K(x_I, y_I, z_I) \\ y_K(x_I, y_I, z_I) \\ z_K(x_I, y_I, z_I) \end{matrix} = \begin{matrix} x_I G + y_I H + z_I J \\ x_I A + y_I B + z_I C \\ x_I D + y_I E + z_I F \end{matrix} \tag{12}$$

where the coefficients are defined as:

$$\begin{aligned}
A &= \cos\theta_I \sin(\psi_I - \psi_K) \\
B &= \cos(\psi_I - \psi_K) \\
C &= \sin\theta_I \sin(\psi_I - \psi_K) \\
D &= \cos\theta_I \sin\theta_K \cos(\psi_I - \psi_K) - \sin\theta_I \cos\theta_K \\
E &= -\sin\theta_K \sin(\psi_I - \psi_K) \\
F &= \sin\theta_I \sin\theta_K \cos(\psi_I - \psi_K) + \cos\theta_I \cos\theta_K \\
G &= \cos\theta_I \cos\theta_K \cos(\psi_I - \psi_K) + \sin\theta_I \sin\theta_K \\
H &= -\cos\theta_K \sin(\psi_I - \psi_K) \\
J &= \sin\theta_I \cos\theta_K \cos(\psi_I - \psi_K) - \cos\theta_I \sin\theta_K
\end{aligned} \tag{13}$$

The velocity potential at a point on the influenced ship I due to the potential at a point on the other ship K is:

$$\phi_K = \int_{bow}^{stern} \frac{m_K}{R_K} + \frac{(d_{yK} + d_{yvK} + d_{yrK})y_K}{R_K^3} + \frac{d_{zK}z_K}{R_K^3}$$

$$= \int_{bow}^{stern} \frac{m_K}{R_K} + \frac{(d_{yK} + d_{yvK} + d_{yrK})(Ax_I + By_I + Cz_I)}{R_K^3}$$

$$+ \frac{(d_{zK})(Dx_I + Ey_I + Fz_I)}{R_K^3} \qquad (14)$$

Because the transformation matrix does not change the magnitude of R, R_I may be substituted for R_K in Equation (14).

2.2 Interaction Forces and Moments Calculation

The interaction forces and moments are calculated by the Lagally theorem using the form derived by Landweber and Yih (Reference 4). The expression for the forces with the added mass and distributed source terms deleted is

$$F_i = -4\pi\rho[\frac{d}{dt} \sum(mx_i + d_i) + \sum\sum_j(mq_i + d_j \frac{\partial q_i}{\partial x_j})] \qquad (15)$$

where $i = x,y,z$; ρ = density of water, x_i = distance along x-,y-,z-axis, $q_i = -\partial\phi/\partial x_i$, and $j = x,y,z$.

$$F_x = \int_{bow}^{stern} -4\pi\rho\left[\frac{d}{dt}(mx_x) + \left(mq_x + (dy+d_{yv}+d_{yr})\frac{\partial q_x}{\partial y} + d_z\frac{\partial q_x}{\partial z}\right)\right]$$

$$F_y = \int_{bow}^{stern} -4\pi\rho\left[\frac{d}{dt}(d_y+d_{yv}+d_{yr}) + \left(mq_y + (d_y+d_{yv}+d_{yr})\frac{\partial q_y}{\partial y}\right.\right.$$

$$\left.\left. + d_z\frac{\partial q_y}{\partial z}\right)\right]$$

$$F_z = \int_{bow}^{stern} -8\pi\rho\left[\frac{d}{dt}(d_z) + \left(mq_z + (d_y+d_{yv}+d_{yr})\frac{\partial q_z}{\partial y} + d_z\frac{\partial q_z}{\partial z}\right)\right]$$

$$\ldots(16)$$

where:

$$q_x = -\frac{\partial\phi}{\partial x}, \quad \frac{\partial q_x}{\partial y} = -\frac{\partial^2\phi}{\partial x\partial y}, \quad \frac{\partial q_x}{\partial z}, = -\frac{\partial^2\phi}{\partial x\partial z}$$

$$q_y = -\frac{\partial\phi}{\partial y}, \quad \frac{\partial q_y}{\partial y} = -\frac{\partial^2\phi}{\partial y^2}, \quad \frac{\partial q_y}{\partial z} = -\frac{\partial^2\phi}{\partial y\partial z}$$

$$q_z = -\frac{\partial\phi}{\partial z}, \quad \frac{\partial q_z}{\partial y} = \frac{\partial q_y}{\partial z}, \quad \frac{\partial q_z}{\partial z} = -\frac{\partial^2\phi}{\partial z^2}$$

which are the partial derivatives of ϕ as defined in Equation (14).

The expression for the moments with the added mass and distributed sources terms deleted is:

$$M_i = -4\pi\rho\left[\frac{d}{dt}\left(\sum(m_b(\phi_o' + d_j x_j) - m_o\phi_b' - d_{bj}(q_{oj}' - u_j)\right.\right.$$

$$\left.\left. + d_{oj}q_{bj}') + e_{ijk}\sum_{jk}(mx_j q_k + d_j q_k + x_j d_l \frac{\partial q_k}{\partial x_l})\right]\right] \qquad (17)$$

where $b = 3+i$, o indicates that the ship is at rest, ' indicates the potential external to the body, j and $l = 1,2,3$, $e_{ijk} = 1$ for ijk in ascending order, -1 for ijk in descending order, and 0 otherwise. The b subscript denotes terms of the velocity potential representing rotation about the x,y,z axes of which only $d_{62} = d_{yr}$ is nonzero, because rotations about the other axes are ignored. The only time derivative term remaining is $d/dt(-d_{62}(q_{o2}' - u_2))$. Because the sources and dipoles are located on the centerline of the ship, $x_2 = x_3 = 0$.

$$M_x = \int_{bow}^{stern} -4\pi\rho[(d_y + d_{yv} + d_{yr})q_z - d_z q_y]$$

$$M_y = \int_{bow}^{stern} -4\pi\rho[-x_1(mq_z + (d_y+d_{yv}+d_{yr})\frac{\partial q_z}{\partial y} + d_z \frac{\partial q_z}{\partial z}) + d_z q_x]$$

$$M_z = \int_{bow}^{stern} -4\pi\rho[x_1(mq_y + (d_y+d_{yv}+d_{yr})\frac{\partial q_y}{\partial y} + d_z \frac{\partial q_y}{\partial z})$$

$$- q_x(d_y+d_{yv}+d_{yr}) - d_{yr}(\frac{d}{dt} q_{o2}') - q_{o2}'(\frac{d}{dt} d_{yr})] \qquad (18)$$

where q'_{o2} is calculated from

$$\phi_o = \int_{bow}^{stern} \frac{m_{Ko}}{R_I} + \frac{d_{yKo}(Ax_I + By_I + Cz_I)}{R_I^{\ 3}}$$

$$+ \frac{d_{zKo}(Dx_I + Ey_I + Fz_I)}{R_I^{\ 3}} \tag{19}$$

where m_{Ko}, d_{yKo}, d_{zKo} are calculated without including d_{yv} or d_{yr}.

2.3 Ship Trajectory Calculations

The ship trajectories are calculated using standard ship equations of motion (Reference 3) in the lateral plane.

$$(m-X_{\dot{u}})\dot{u} = X_o + X_u(\Delta u) + X_{uu}(\Delta u)^2 + X_{uuu}(\Delta u)^3$$

$$+ X_{vv}v^2 + (X_{vr}+m)vr + X_{v\delta}v\delta + (X_{rr}+mx_G)r^2$$

$$+ X_{r\delta}r\delta + X_{\delta\delta}\delta^2 + X_{\delta\delta u}\delta^2\Delta u + X_{int}$$

$$(m-Y_{\dot{v}})\dot{v} + (mx_G-Y_{\dot{r}})\dot{r} = Y_o + Y_{ou}(\Delta u) + Y_v v$$

$$+ Y_{vvv}v^3 + Y_{vu}v\Delta u + Y_{rvv}rvv + Y_{\delta vv}\delta vv$$

$$+ Y_{vr\delta}vr\delta + Y_{rrr}r^3 + Y_r r$$

$$+ Y_{vrr}vrr + Y_{\delta rr}\delta rr + Y_{\delta\delta\delta}\delta^3 + Y_\delta \delta$$

$$+ Y_{\delta u}\delta\Delta u + Y_{v\delta\delta}v\delta^2 + Y_{r\delta\delta}r\delta^2 + Y_{\delta uu}\delta\Delta u^2 + Y_{int}$$

(20)

$$(mx_G-N_{\dot{v}})\dot{v} + (I_z-N_{\dot{r}})\dot{r} = N_o + N_{ou}(\Delta u) + N_v v$$

$$+ N_{vvv}v^3 + N_{vu}v\Delta u + N_{rvv}rvv + N_{\delta vv}\delta vv$$

$$+ N_{vr\delta}vr\delta + N_{rrr}r^3 + N_r r$$

$$+ N_{vrr}vrr + N_{\delta rr}\delta rr + N_{\delta\delta\delta}\delta^3 \; N_\delta \delta$$

$$+ N_{\delta u}\delta\Delta u + N_{v\delta\delta}v\delta^2 + N_{r\delta\delta}r\delta^2 + N_{\delta uu}\delta\Delta u^2 + N_{int}$$

<u>Note</u>: $Y_{v|v|}$, $Y_{r|v|}$, $Y_{\delta|v|}$, $N_{v|v|}$, $N_{|r|v}$, and $N_{\delta|v|}$ are sometimes used instead of Y_{vvv}, Y_{rrv} or Y_{vvr}, $Y_{\delta\delta v}$ or $Y_{vv\delta}$, N_{vvv}, N_{rrv}, or N_{vvr}, $N_{\delta\delta v}$ or $N_{vv\delta}$.

where m is the mass of the ship, I_z is the moment of inertia in yaw, x_G is the longitudinal distance from amidships to the center of gravity, X_o, Y_o, and N_o are the forces and moment in straight ahead motion, and X_u, Y_v, N_r, etc. are the partial derivatives of X, Y, and N in straight ahead motion (for example, $Y_v = \partial Y/\partial v$, $N_{vr\delta} = \partial^3 N/\partial v \partial r \partial \delta$), Δu is the change from the initial speed, δ is the rudder angle, and X_{int}, Y_{int}, and N_{int} are the interaction forces and moment as defined in Equations (16) and (18). The Equations (20) above are solved for the accelerations $\dot{u}$, $\dot{v}$, and $\dot{r}$. The velocities are calculated for the next time step by

$$
\begin{aligned}
u(t+\Delta t) &= u(t) + (\Delta t)\dot{u}(t) \\
v(t+\Delta t) &= v(t) + (\Delta t)\dot{v}(t) \\
r(t+\Delta t) &= r(t) + (\Delta t)\dot{r}(t)
\end{aligned}
\tag{21}
$$

The ship trajectories are calculated by

$$
\begin{aligned}
x_o(t+\Delta t) &= x_o(t) + (\Delta t)[u(t)\cos\psi + v(t)\sin\psi] \\
y_o(t+\Delta t) &= y_o(t) + (\Delta t)[u(t)\sin\psi + v(t)\cos\psi] \\
\psi(t+\Delta t) &= \psi(t) + (\Delta t)r(t)
\end{aligned}
\tag{22}
$$

The static sinkage and trim of the ship are calculated by

$$\text{Sink} = Z_{int}/\text{TPI}$$
$$\text{Trim} = M_{int}/\text{MT1} \tag{23}$$

where $Z_{int} = F_z$ of Equation (16), $M_{int} = M_y$ of Equation (18), TPI = tons per inch immersion, MT1 = moment to trim one inch.

2.4 Ship Control Calculations

It is essential to control the motions of the ships to avoid collisions and to simulate underway replenishment operations. When the ships are far apart, it is sufficient to maintain speed and heading. When the one ship overlaps the other lengthwise, it is necessary to control both ships also on the basis of relative motion, relative velocity, and relative heading.

Using linear proportional-plus-derivative control of the heading (Reference 3), the change in rudder angle is

$$\text{DR} = \text{K1C}(\psi\text{-Head-rDlag}) + \text{K2R}(\text{r-}\dot{\text{r}}\text{Dlag}) \tag{24}$$

where K1C is the gain in degree rudder per degree of heading

error, Head is the commanded heading, Dlag is the delay in moving the rudder, and K2R is the gain in degrees rudder per degree per second of yaw rate. Using the same type of control on speed, the change in speed is:

$$\text{Ucmmd} = \text{K6U}(u_o - u + \dot{u}\text{Ulag}) + \text{K7A}(-\dot{u} + \ddot{u}\,\text{Ulag}) \qquad (25)$$

where K6U is the gain in feet per second (fps) per fps of speed error, u_o is the commanded speed, Ulag is the delay in changing speed, K7A is the gain in fps per feet per second^2 of acceleration ($\dot{u}$), and $\ddot{u} = d\dot{u}/dt$. When the ships overlap lengthwise the change in rudder angle to maintain a given lateral separation and the same heading becomes:

$$\begin{aligned}
DR_1 = {} & \text{K1C}(\psi_1 - \text{Head} + \psi_1 - \psi_2 - (r_1 + r_1 - r_2)\text{Dlag}) \\
& + \text{K2R}(r_1 + r_1 - r_2 - (\dot{r}_1 + \dot{r}_1 - \dot{r}_2)\text{Dlag}) \\
& + \text{K3Y}(y_{rel_1} + \text{PassSide} - [(v_1 - v_2)\cos\psi_2 \\
& - (u_1 - u_2)\sin\psi_2)\text{Dlag}] \\
& + \text{K4V}[(v_1 - v_2)\cos\psi_2 - (u_1 - u_2)\sin\psi_2
\end{aligned}$$

$$- [(\dot{v}_1 - \dot{v}_2)\cos\psi_2 - (\dot{u}_1 - \dot{u}_2)\sin\psi_2)\text{Dlag}] \quad (26)$$

where the subscripts 1 and 2 indicate Ships 1 and 2 respectively, K3Y is the gain in degrees rudder per foot of relative separation error, $y_{rel} = (y_1 - y_2)\cos\psi_2 - (x_1 - x_2)\sin\psi_2$ is the relative lateral separation, Pass is the commanded ship separation distance, Side indicates on which side Ship 2 is relative to Ship 1, and K4V is the gain in degrees rudder per fps of relative lateral separation.

When underway replenishment is simulated, it is necessary to match ship speeds and to reduce their longitudinal separation to zero. The change in speed of the ship to be replenished becomes

$$\text{Ucmmd} = \text{K5X}(-x_{rel_2} + u_2\text{Ulag}_2) + \text{K6U}(u_1 - u_2 + \dot{u}_2\text{Ulag})$$

$$+ \text{K7A}(-\dot{u}_2 + \ddot{u}_2\text{Ulag}) \quad (27)$$

where K5X is the gain in fps per foot of longitudinal separation error, and $x_{rel_2} = (x_2 - x_1)\cos\psi_1 + (y_2 - y_1)\sin\psi_1$ is the relative longitudinal separation.

To make the ship control more like a helmsman, the change in speed or rudder angle is ignored if it is below a given threshold. The rudder is moved toward the commanded

angle at the given rudder rate and is limited by the maximum rudder angle. The ship speed is changed toward the commanded speed at the given acceleration or deceleration rate. During simulation of replenishment operations the ships remain alongside until it is time to break when the replenished ship accelerates to the break speed and turns to the break heading when its stern clears the bow of the replenishment ship.

CHAPTER 3

DISCUSSION OF RESULTS

3.1 Comparison with Model Test Results

Model test results were used to determine the proper formulation of the body radius and to indicate the accuracy of the theory.

In Reference 1, the theory for the interaction forces between ships was initially developed using as the body radius, R_b, the radius of a semicircle with area equal to the ship sectional area for each ship station. It was then concluded on the basis of comparison with model test results that closer correlation resulted when the body radius was taken as the average of the equivalent sectional radius described above and the actual beam of the section.

In this study the first approach was to extend the above averaging approach. The lateral body radius was taken as average radius just described, while the vertical body radius was the average of the equivalent sectional radius and the actual ship draft. These lateral and vertical body radii were used to determine the strength of the lateral and vertical dipoles, respectively. The average of the lateral and vertical radii was used to calculate the source strength at each station. This formulation for the body radius was compared with the equivalent sectional radius

and with model test results in Figures 2, 3, 6, and 7. The model test data in Figures 2 and 3 are taken from Reference 5, which reports interaction force tests of models of the British ships KING GEORGE V, a battleship, and OLNA, an oiler. The interaction moment data was plotted in Reference 5 by taking the moment about a point located two-tenths of the length of the ship from the bow. The moment has been shifted to amidships in Figures 2, 3, 4, and 5 to correspond with the theoretical moment and with other model test moment data. The model test data in Figures 6 and 7 are taken from Reference 6, which reports interaction forces for a model of a U.S. Navy AOE-1 Class large support ship while near a CVA-58 Class carrier. The figures indicate that using the equivalent sectional radius gives equal or better correlation with model test data than using the averaged radius described above. Using the equivalent radius to determine the source strength and the beam and draft to determine the lateral and vertical dipole strengths, respectively, led to the same conclusion. The equivalent radius is used for all subsequent work. Figures 4 and 5 show that the shallow water theory agrees with the deep water theory of Reference 1.

The theoretical interaction forces tended to be less than the model test data, while the moments tended to be

greater than the model test data. The theory did not account for much of the assymmetry shown in the model test data between the passing ship located behind the lead ship compared to it being ahead. This is due in part to the neglect of wake effects by the theory.

The only model test data for interaction forces in shallow water were found in Reference 7, which reports on forces on ship models in a model of the Panama Canal. The presence of the canal bank was modeled theoretically by locating the second ship at a lateral separation equal to twice the distance to the canal bank from the first ship. The longitudinal separation was zero. The sectional areas, beams, and drafts of the Mariner were used to represent the medium fast cargo ship in Figure 8, while the AO-177 represented the large fast cargo ship in Figure 9. The theoretical interaction forces and moments were markedly lower than the model test values. The theoretical moment is typically small at zero longitudinal separation. The water depth is only about 40 percent greater than the draft of the ship in both cases. The fact that the model boundary layer is thicker than that of the ship tends to increase the interaction effects. The theory neglects the effects of boundary layer. The difference between self-propelled model and the towed model in Figure 9 indicates

that the propeller has a significant effect on the interaction forces and moments, which is neglected by the theory.

3.2 Rudder Design Effects on Replenishment Operations

The replenishment operation was selected to study the effects of increasing the rudder rate or its effectiveness, since ships are typically in closest proximity under these conditions. A Navy oiler and destroyer were selected as typical ships which would be involved in replenishment operations and for which model test data were available. The data for the AO-177 oiler were taken from Reference 8. The simulations started the ships at a lateral separation of 100 feet and a longitudinal separation of 550 feet in water 300 feet deep. The changes in the interaction forces and moments caused by the changes in lateral separation, sway velocity, and yaw rate of the ships in motion are indicated in Figure 10. Several simulation runs with increasing rudder control gains were required to select gains to prevent collision of the ships. Because the displacement of the destroyer is approximately 3.5 times smaller than that of the oiler, its rudder control gains were increased by a factor of 3.5 over those of the oiler as shown in Table 1. To study the effects of rudder

design changes the rudder rate was increased by 50 percent for one simulation and the rudder effectiveness was increased by 50 percent for another. The increased rudder effectiveness was obtained by increasing only the coefficients which were explicit functions of rudder angle, while neglecting the effects of increased rudder size on other coefficients. To study the effects of water depth, the simulation with standard rudders was repeated in water with a depth of 60 feet. The above simulations are summarized in Table 2, which contains the mean values and standard deviations of the lateral separation, the relative heading, and the rudder angles of each ship. The trajectories of the two ships are shown for the case of increased rudder effectiveness using low gains in Figure 11, for the standard rudder using the final gains in Figure 12, for the increased rudder effectiveness using the final gains in Figure 13, and for the case of 60 foot water depth in Figure 14.

Because each simulation was characterized by control errors and overshoots, the rudder control gains which were sensitive to the rate of change of heading and lateral separation were increased from eight to ten times to fifty times the gains sensitive to heading and lateral separation (Table 1). These final gains produced significant

improvement in the control of lateral separation and relative heading and some reduction in rudder activity for both the standard rudder and increased effectiveness cases (Table 2). However, the rudders were unable to provide the corrective action quickly enough to prevent the errors from increasing until large rudder angles were reached, which accounts for the large standard deviations in rudder angle. While the ship interaction forces and moments were strong enough to initiate the errors, the forces and moments generated by the motions of the ships became dominant. The changes in lateral separation, heading error, and rudder activity due to the increased rudder control gains were significantly greater than those due to increased rudder rate, rudder effectiveness, or water depth. Contrary to the premise of this study that increases in rudder rate and effectiveness should improve the control of the ship, the mean errors in lateral separation and relative heading were increased, while the standard deviations of the errors generally decreased slightly. The shallower water depth had little effect on the errors or rudder activity.

TABLE 1

Rudder Control Gains

Ship	Gain	Heading deg/deg	Yaw Rate deg/deg/sec	Y Separation deg/ft	V Velocity deg/ft/sec
Oiler	Low	5.0	40.	.5	5.0
Destroyer	Low	17.5	140.	1.75	17.5
Oiler	Final	4.0	200.	.5	25.0
Destroyer	Final	14.0	700.	1.75	87.5

TABLE 2

Separation and Heading Errors and Rudder Activity

Condition	Gain	Separation feet Mean/S.D.*	Heading degrees Mean/S.D.*	Rudder 1 degrees Mean/S.D.*	Rudder 2 degrees Mean/S.D.*
Standard Rudder Rate and Size	Low	100/22	3.5/2.4	-6.8/15.2	-1.3/19.4
	Final	99/17	1.7/1.4	-4.2/13.0	-0.7/15.7
Rate 50% Higher	Final	71/14	1.8/1.3	-5.4/14.2	-0.3/18.9
Size 50% Larger	Low	137/45	5.5/5.2	-2.4/20.6	1.2/19.8
Size 50% Larger	Final	94/12	2.9/2.1	-2.8/11.1	-0.3/16.5
Standard 60 ft Depth	Final	85/12	1.6/1.2	-6.2/12.7	-1.0/15.6

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- The radius of the body representing the ship at each station should be the radius of a semicircle of area equal to the sectional area of the station.

- The mathematical model tends to underpredict the ship interaction forces and overpredict the interaction moment in deep water.

- The mathematical model underpredicts the ship interaction forces and moments in shallow water.

- Changes in the rudder control sensitivities have much larger effects on the simulation of underway replenishment than changes in rudder effectiveness or rate.

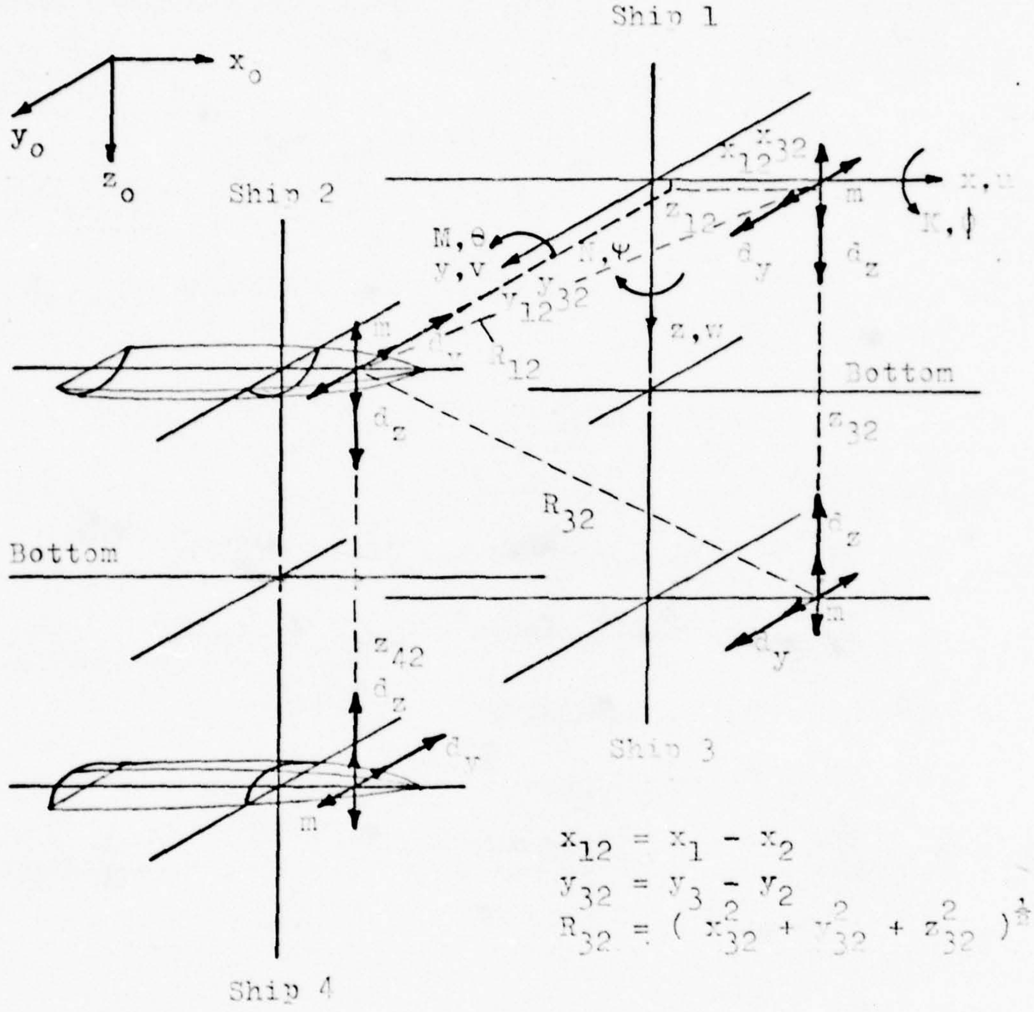
- Increases in the rudder effectiveness or rate resulted in no significant improvement in ship control during underway replenishment in the cases simulated.

4.2 Recommendations

- The mathematical model should be extended to account for the effects of boundary layer, wake, and propeller.

- The rudder control logic should be improved and a procedure for selection of control gains should be defined.

- The speed control logic should be extended to include propeller and propulsion machinery dynamics as in Reference 9.



$$x_{12} = x_1 - x_2$$
$$y_{32} = y_3 - y_2$$
$$R_{32} = (x_{32}^2 + y_{32}^2 + z_{32}^2)^{\frac{1}{2}}$$

Figure 1. Coordinate System and Sources and Dipoles

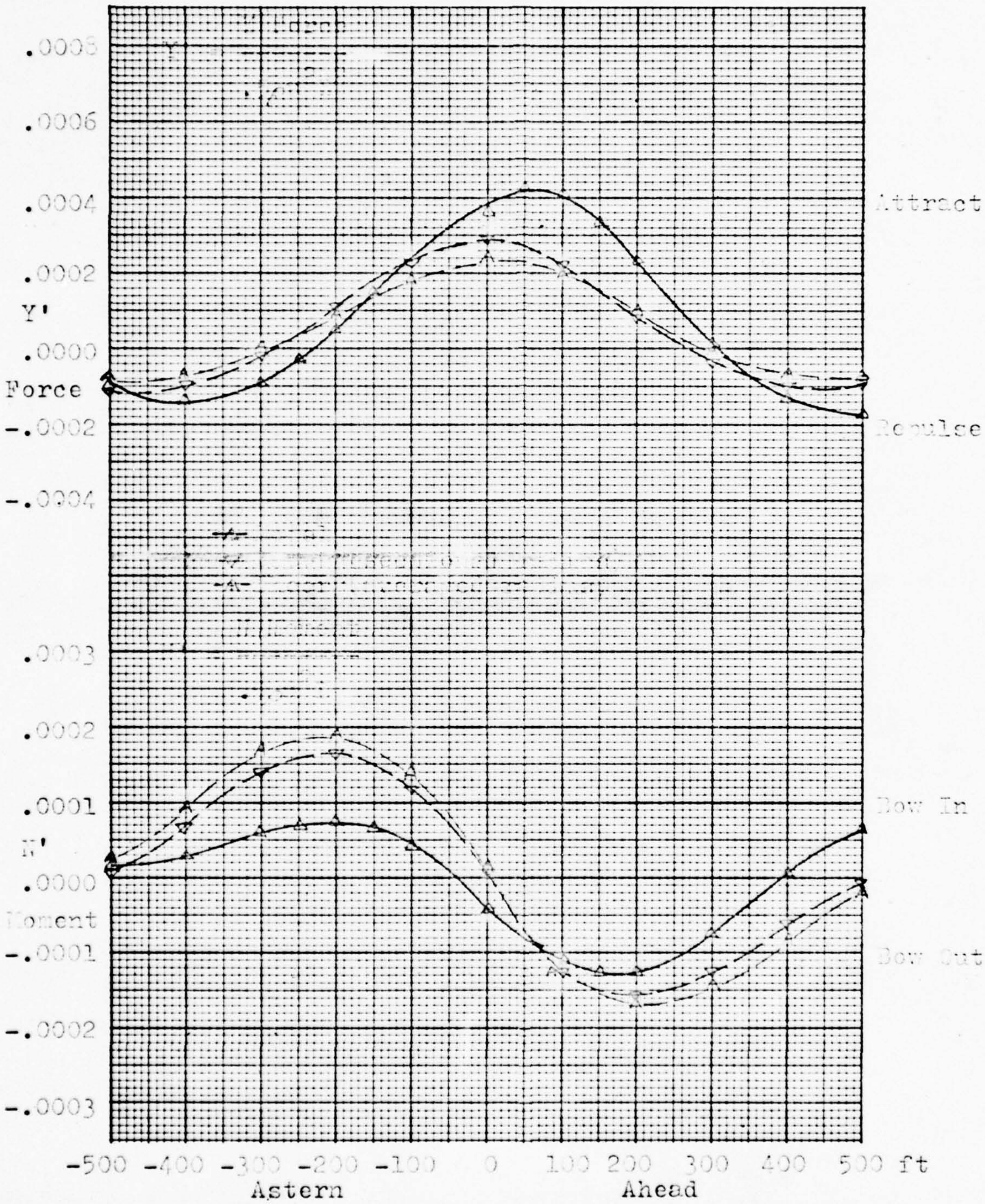


Figure 2. King George V at 15 knots at 50 feet separation.

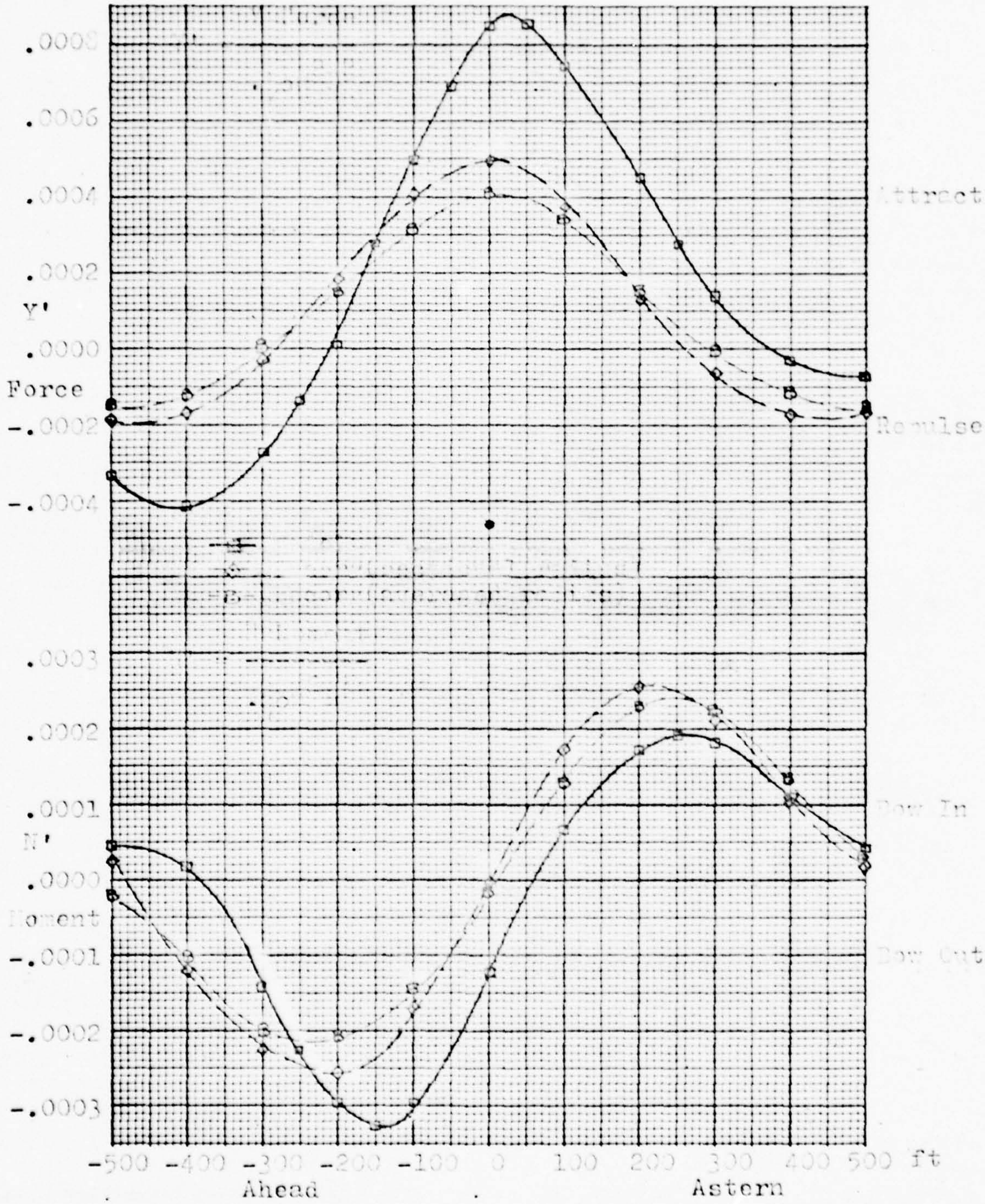


Figure 3. Olna at 15 knots at 50 feet separation.

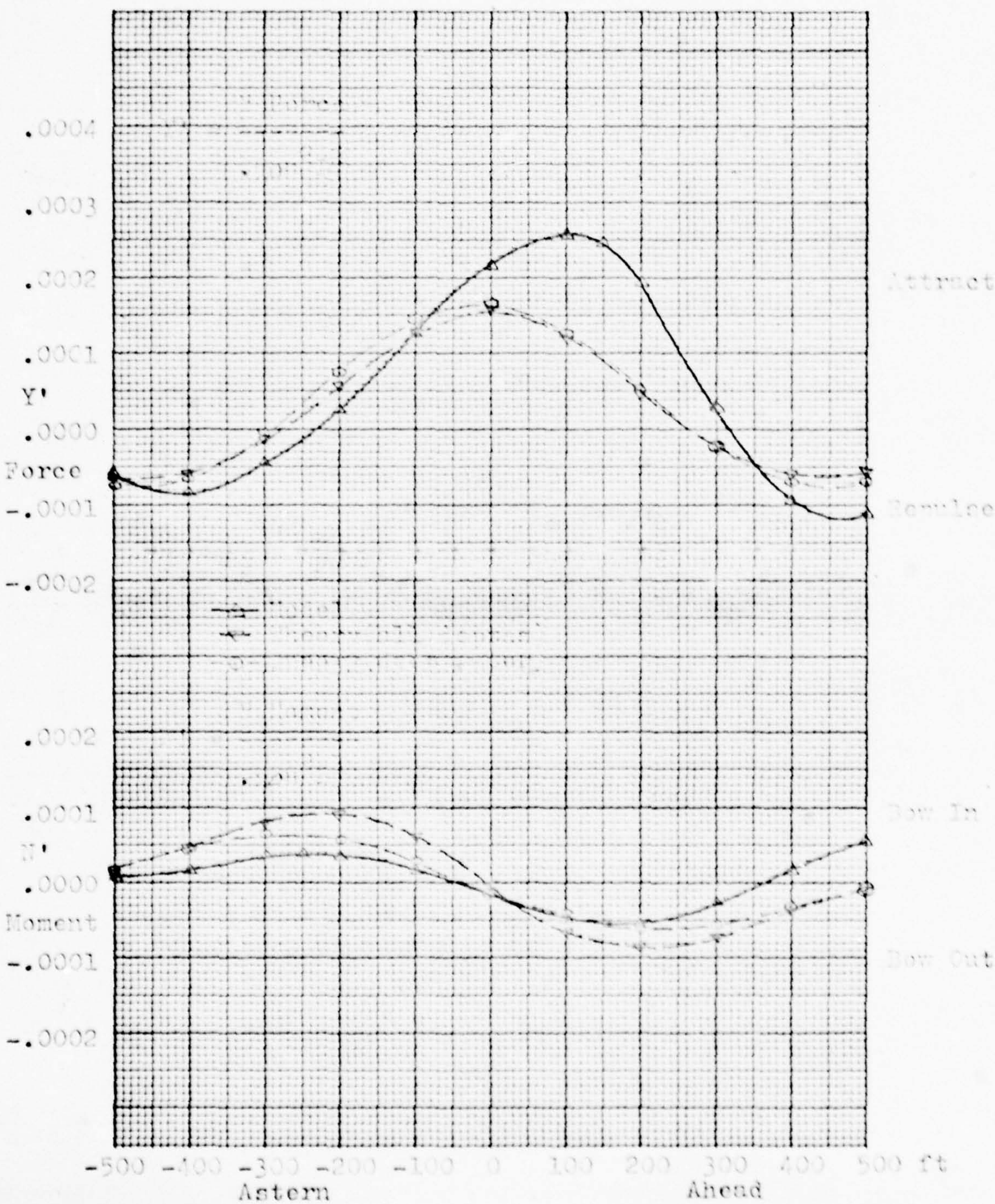


Figure 4. King George V at 15 knots at 100 feet separation.

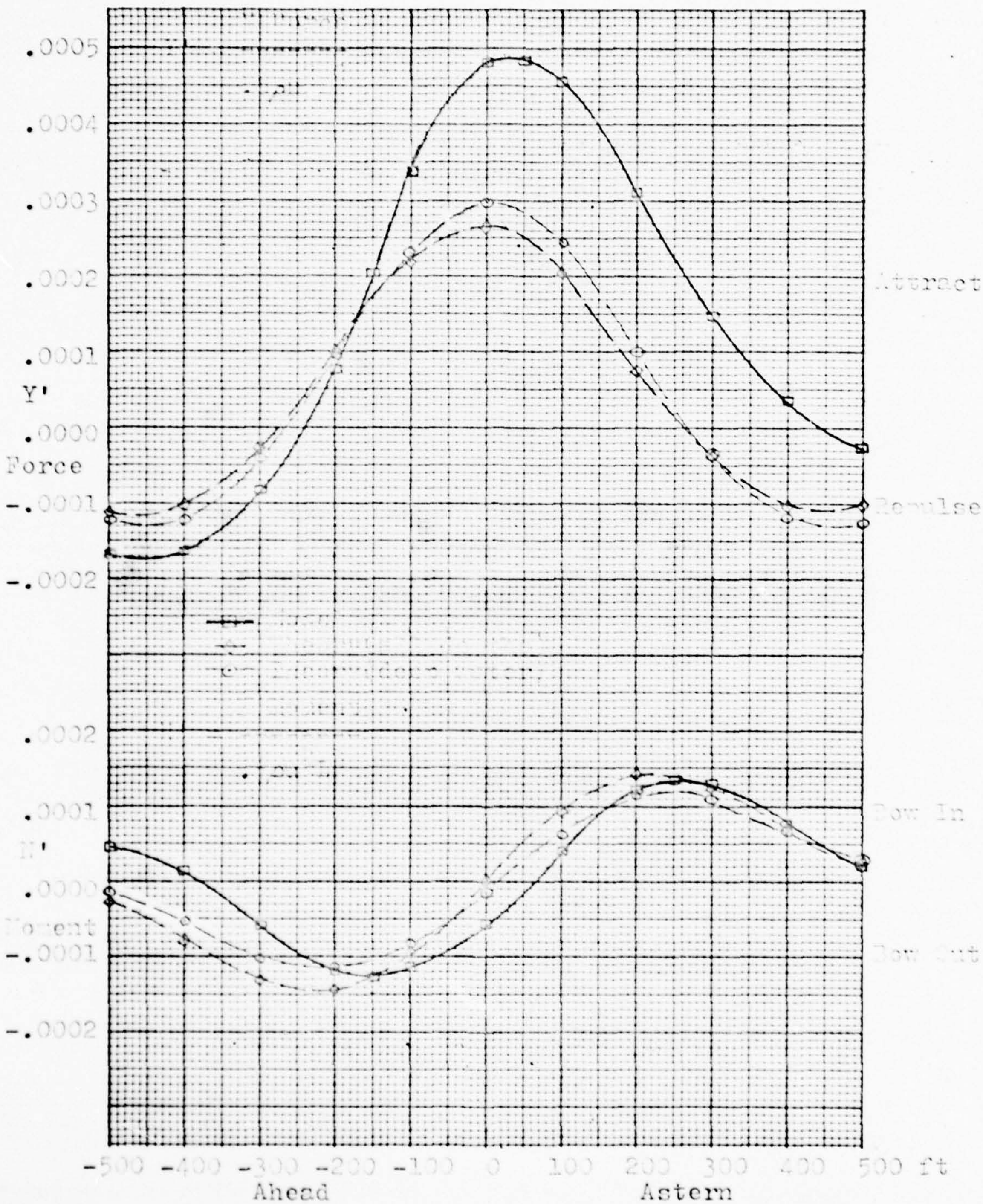


Figure 5. Olna at 15 Knots at 100 feet separation.

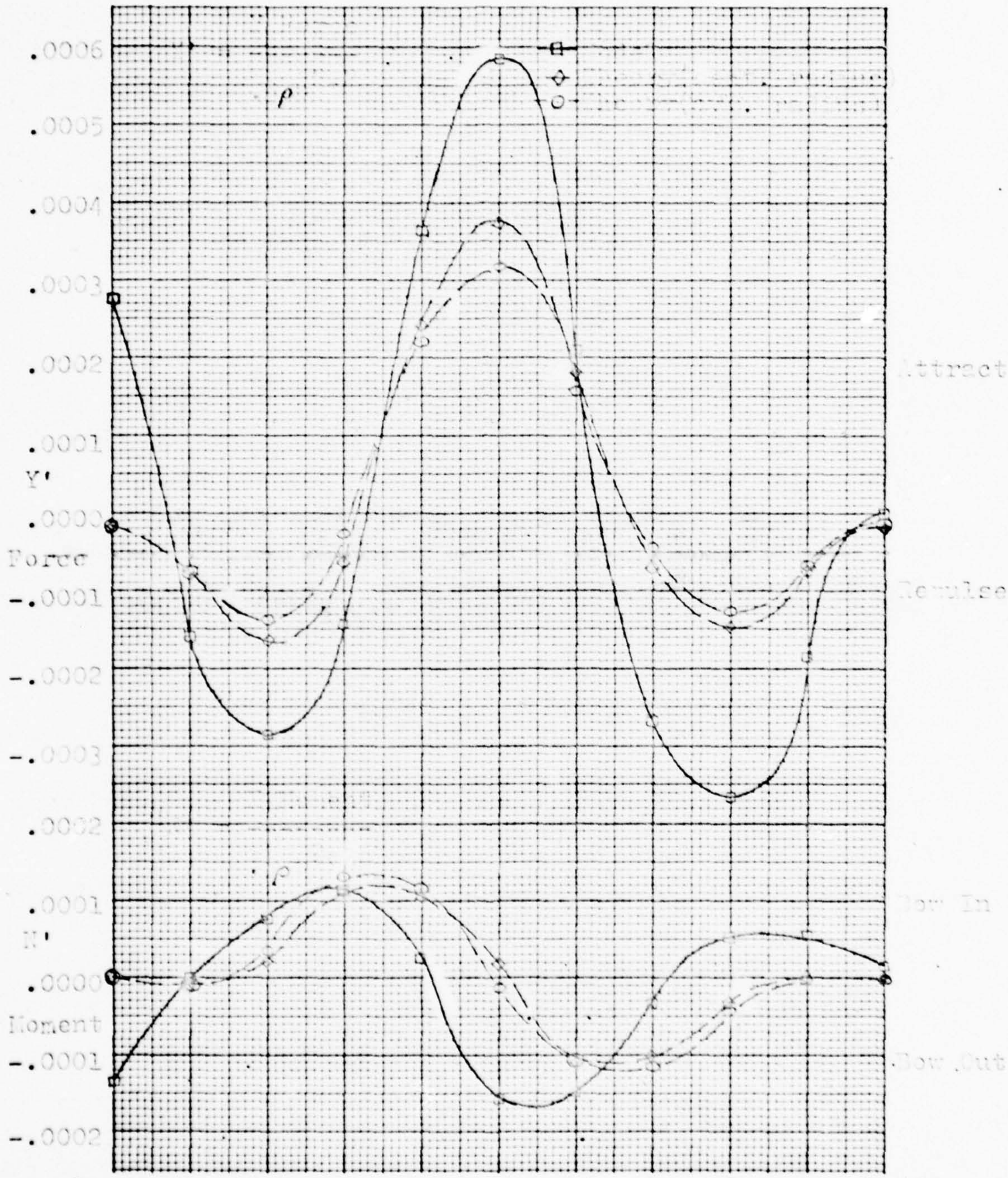


Figure 6. AOE-1 at 15 knots at 50 feet separation.

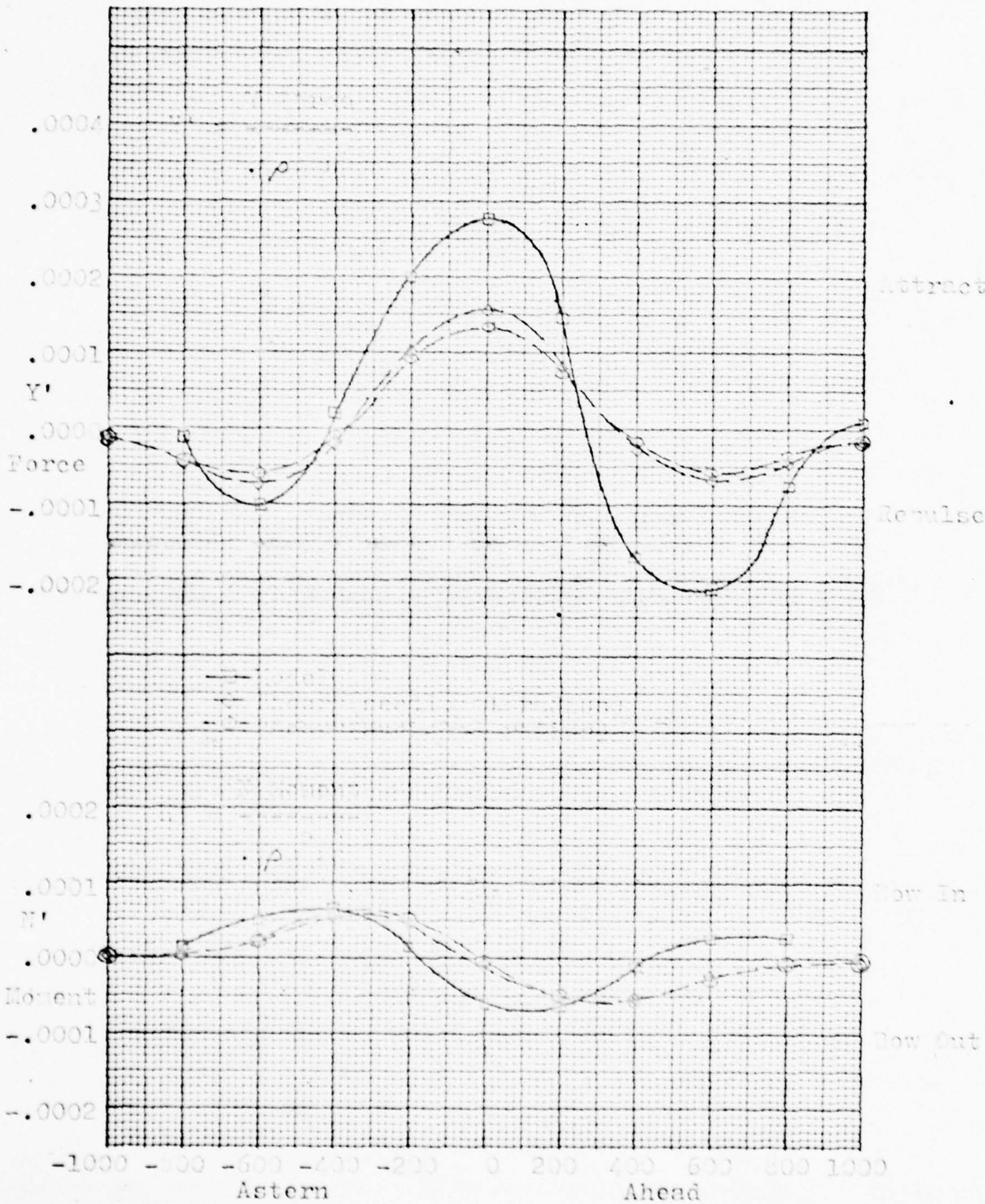


Figure 7. AOE-1 at 15 knots at 150 feet separation.

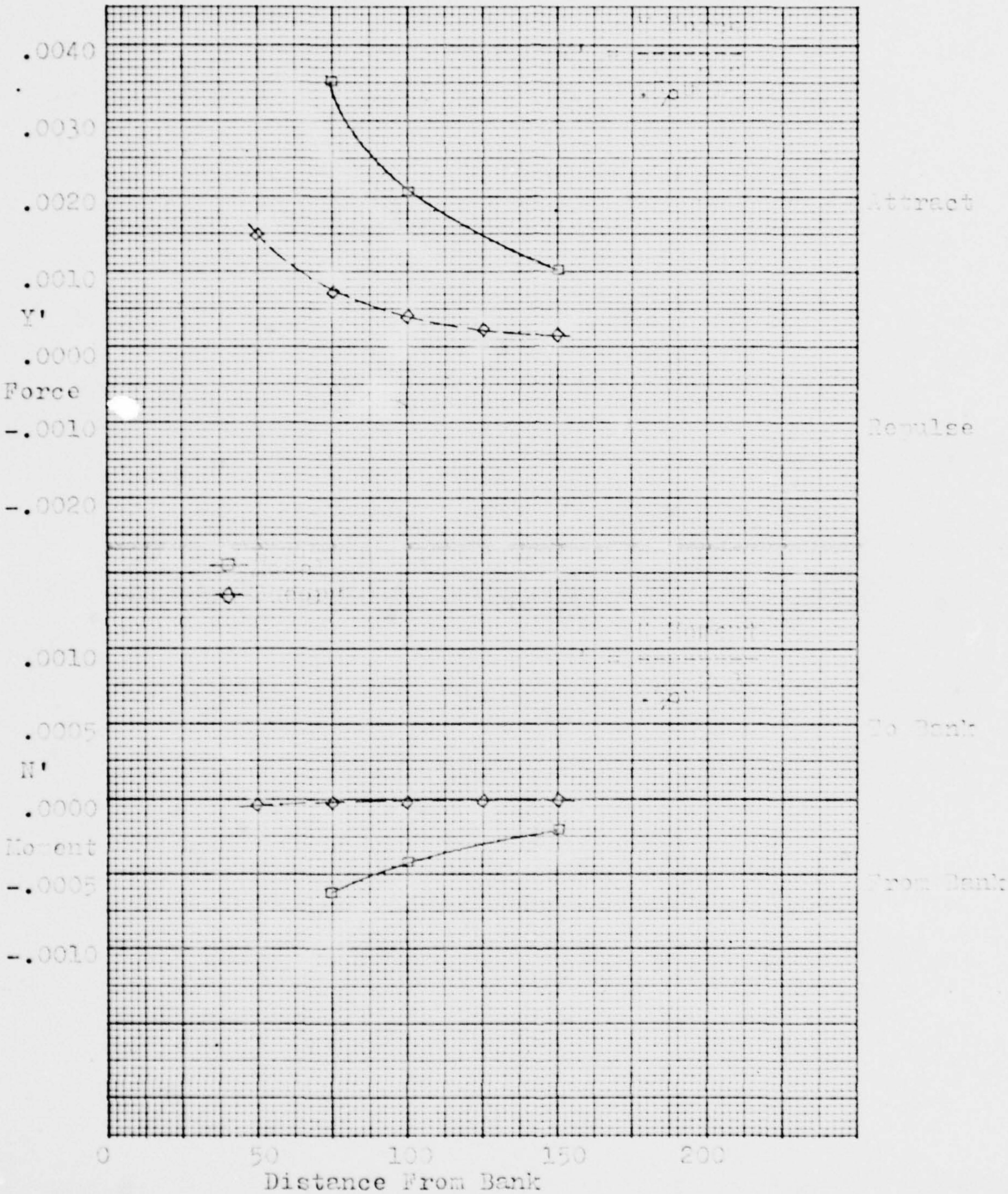


Figure 8. Medium Fast Cargo Ship at 6 knots in 42 feet of water.

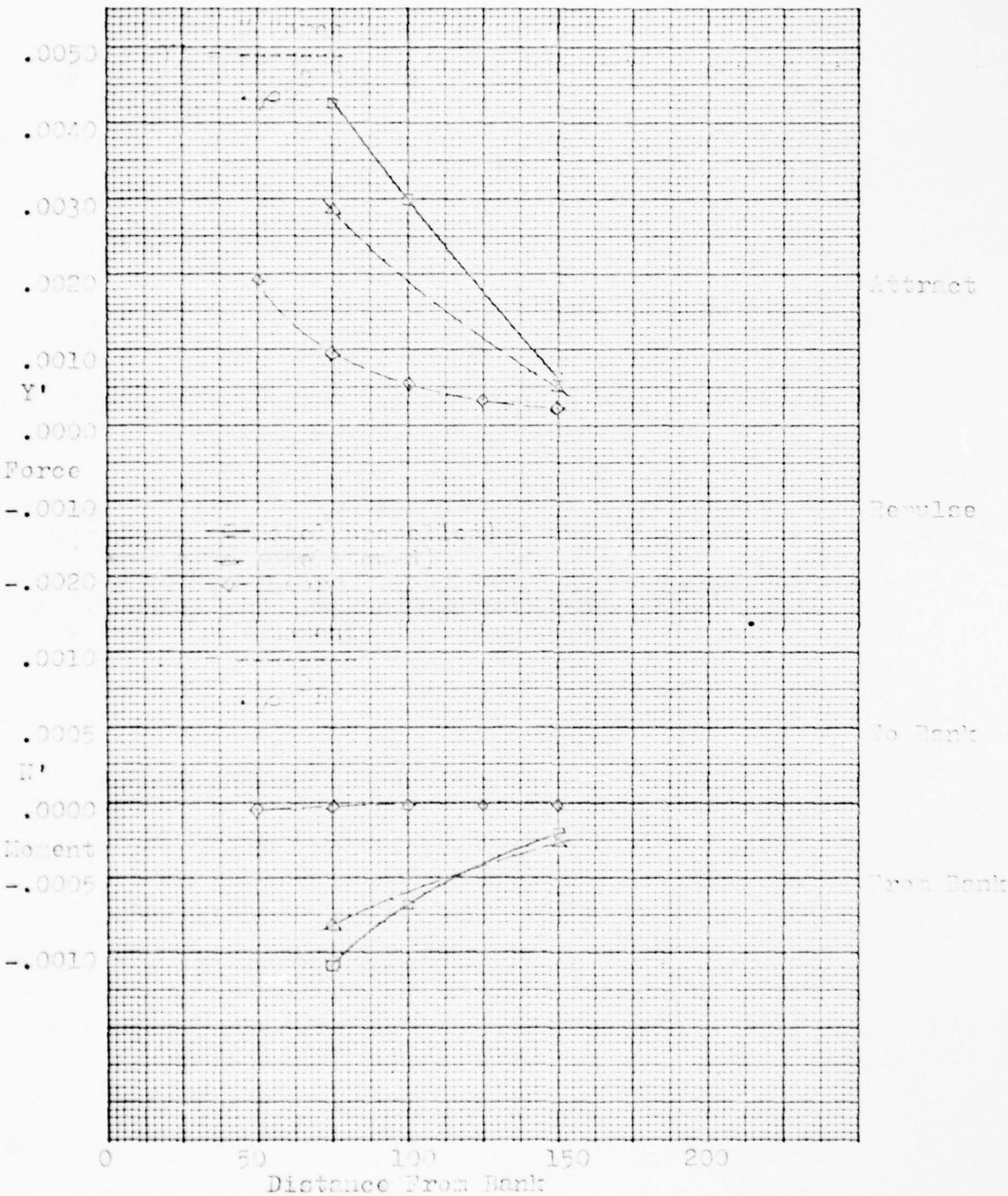


Figure 9. Large Fast Cargo Ship at 6 knots in 47 feet of water.

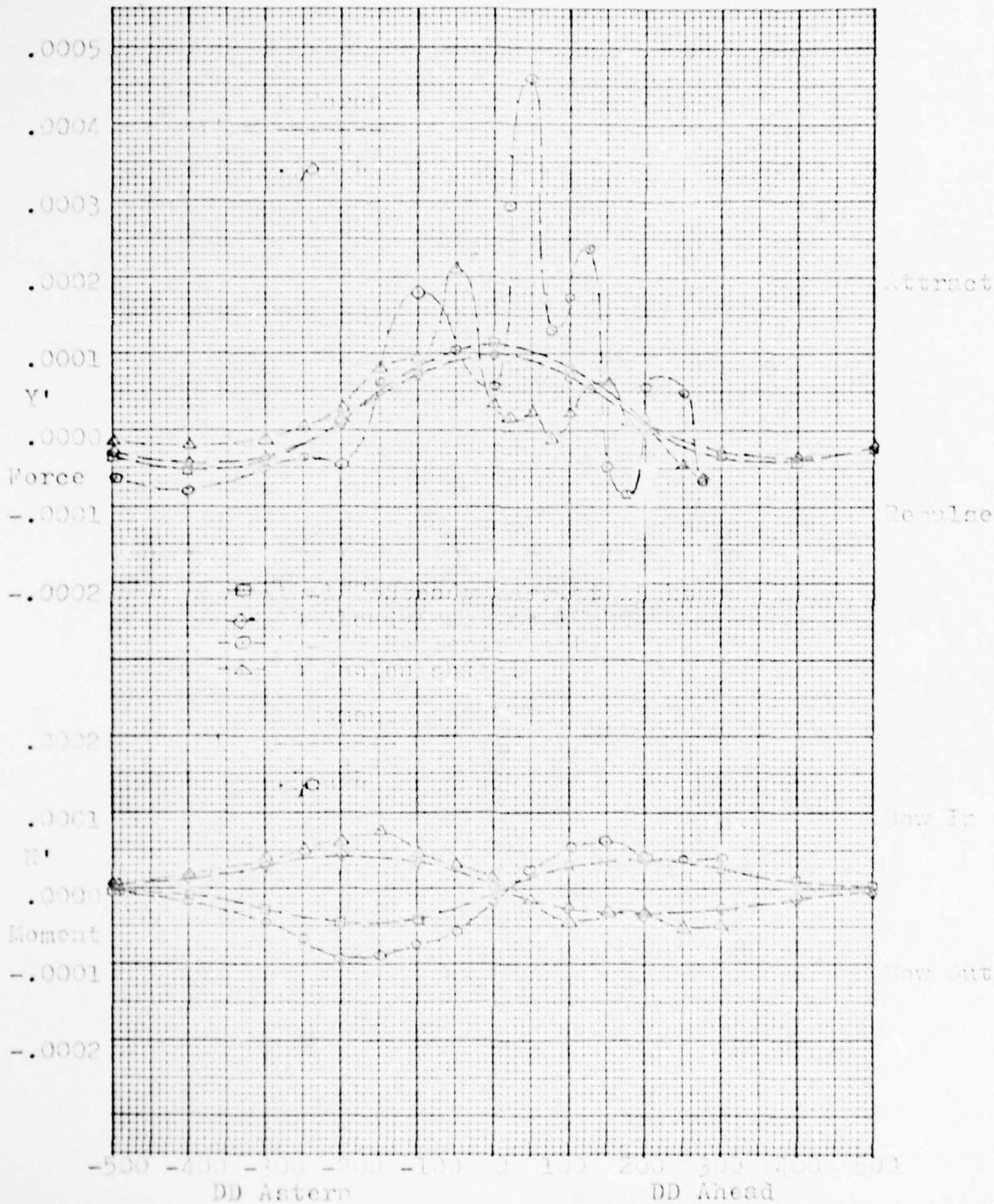
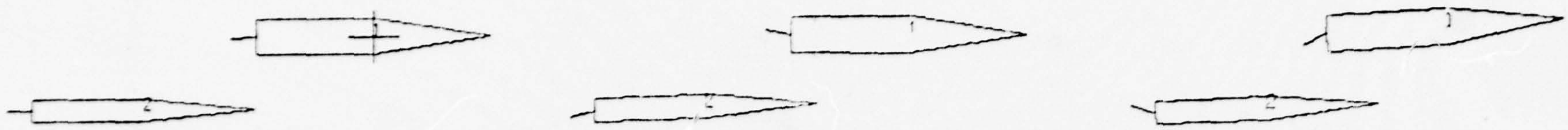


Figure 10. AO-177 and DD Steady pass and Replenishment at 100 ft.

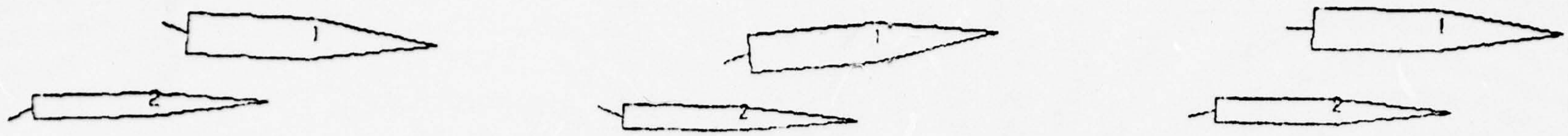


TIME=0.	TIME=20.	TIME=40.
PSI(1)=0.0	PSI(1)=0.3	PSI(1)=-3.3
DR(1)=-4.	DR(1)=10.	DR(1)=-26.
PSI(2)=0.0	PSI(2)=-1.6	PSI(2)=-2.4
DR(2)=0.	DR(2)=-15.	DR(2)=22.
Y2-Y1=172.	Y2-Y1=170.	Y2-Y1=193.

Ship 1 = AO-177 Oiler

Ship 2 = Destroyer

Figure 11 a. Underway Replenishment with Increased Rudder Effectiveness and Low Rudder Gains.

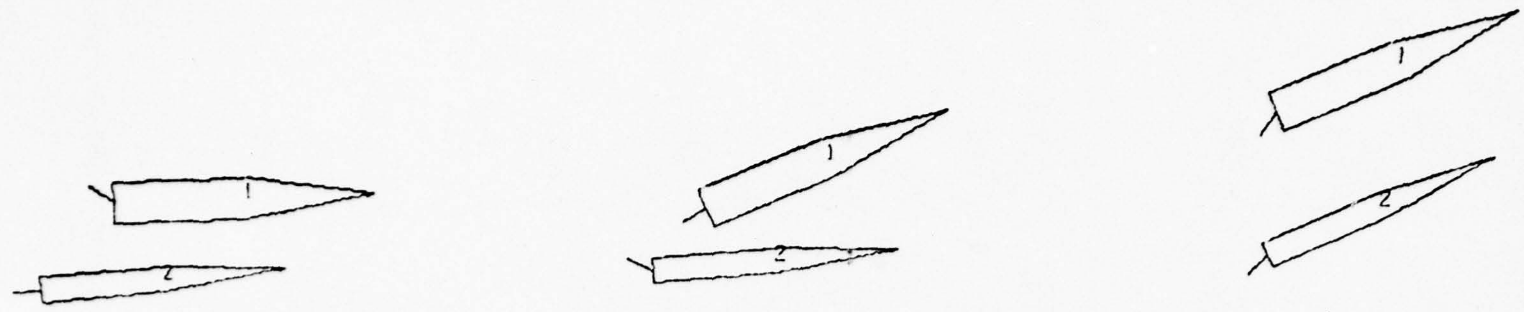


TIME=60.
PSI(1)=2.9
DR(1)=19.
PSI(2)=-1.5
DR(2)=-27.
Y2-Y1=148.

TIME=80.
PSI(1)=-5.0
DR(1)=-17.
PSI(2)=0.6
DR(2)=22.
Y2-Y1=170.

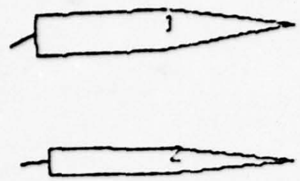
TIME=100.
PSI(1)=1.1
DR(1)=1.
PSI(2)=0.6
DR(2)=-15.
Y2-Y1=179.

Figure 11 b. Continued.

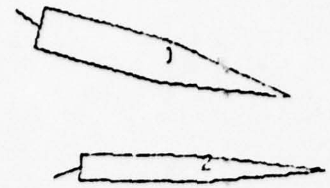


TIME=120.	TIME=140.	TIME=160.
PSI(1)=-1.5	PSI(1)=-21.8	PSI(1)=-22.0
DR(1)=35	DR(1)=-10.	DR(1)=-35.
PSI(2)=-4.8	PSI(2)=-4.5	PSI(2)=-23.1
DR(2)=-0.	DR(2)-30.	DR(2)=-22.
Y2-Y1=171.	Y2-Y1=215.	Y2-Y1=304.

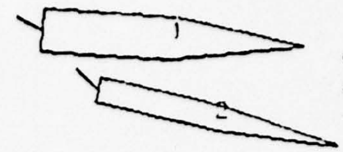
Figure 11 c. Continued.



TIME=180.
PSI(1)=-1.1
DR(1)=-25.
PSI(2)=0.6
DR(2)=-8.
Y2-Y1=278.

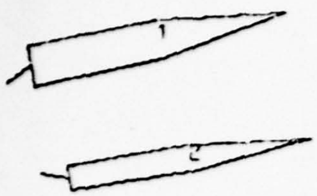


TIME=200.
PSI(1)=15.9
DR(1)=20
PSI(2)=1.6
DR(2)=-22.
Y2-Y1=223.

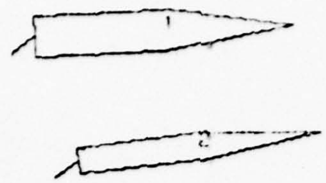


TIME=220.
PSI(1)=4.7
DR(1)=21.
PSI(2)=14.2
DR(2)=30.
Y2-Y1=170.

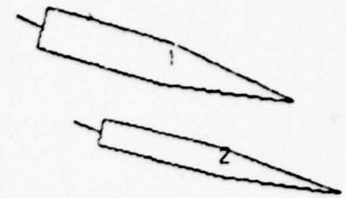
Figure 11 d. Continued.



TIME=240.
PSI(1)=-11.5
DR(1)=-23.
PSI(2)=-8.5
DR(2)=17.
Y2-Y1=252.



TIME=260.
PSI(1)=-2.1
DR(1)=-35.
PSI(2)=-5.3
DR(2)=-30.
Y2-Y1=245.



TIME=280.
PSI(1)=17.0
DR(1)=10.
PSI(2)=14.0
DR(2)=8.
Y2-Y1=206.

Figure 11 e. Continued.

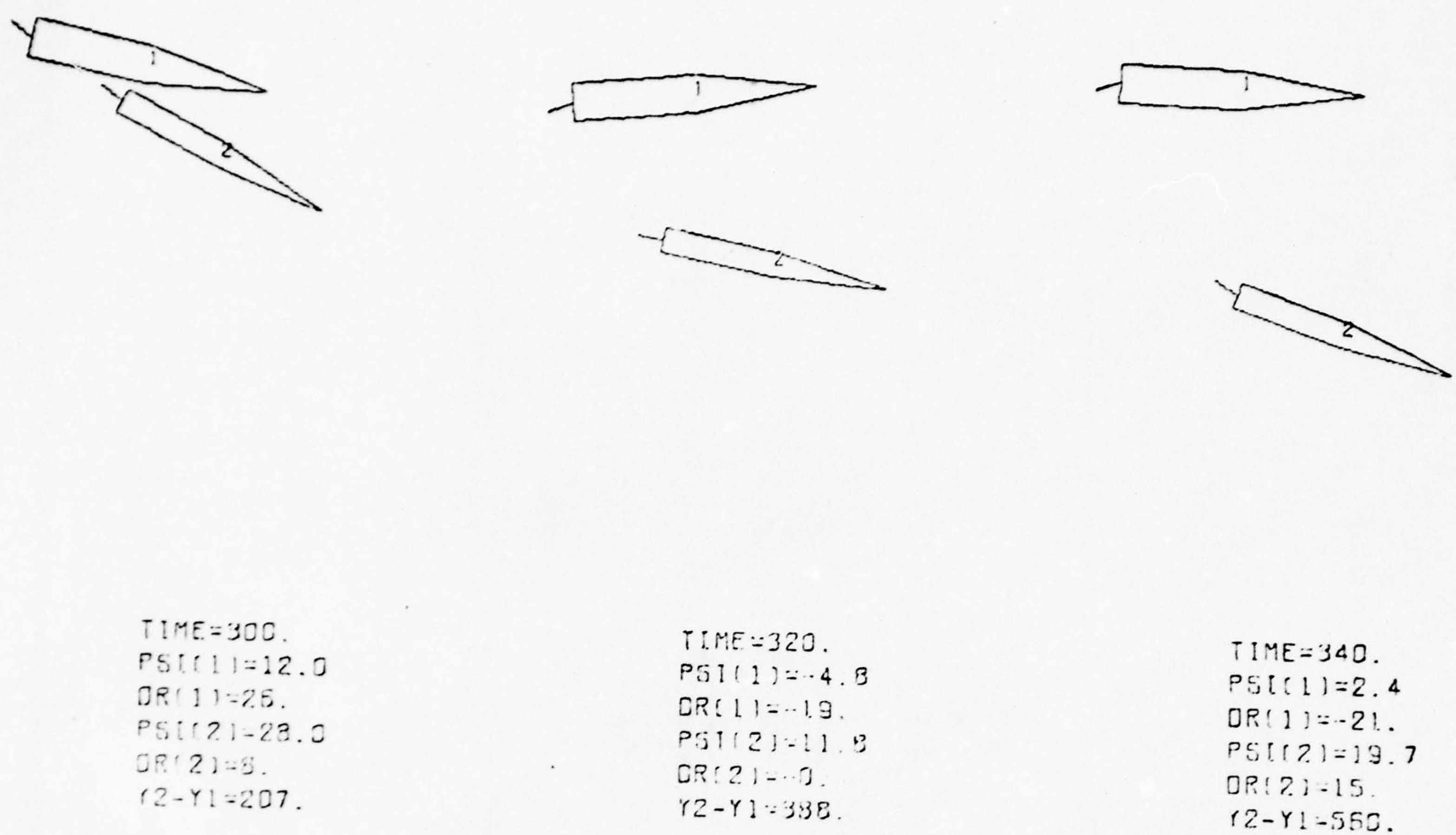


Figure 11 f. Concluded.

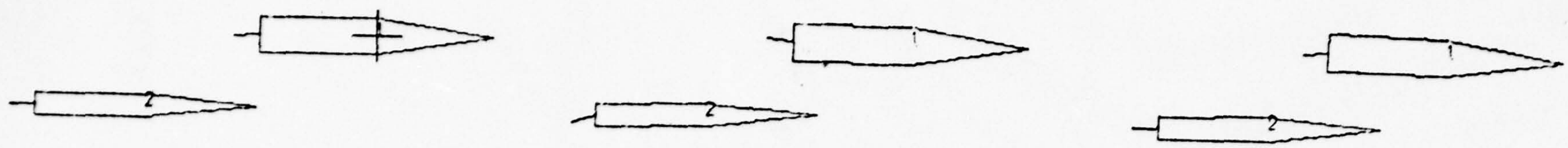


Figure 12 a. Underway Replenishment with Standard Rudder and Gains.

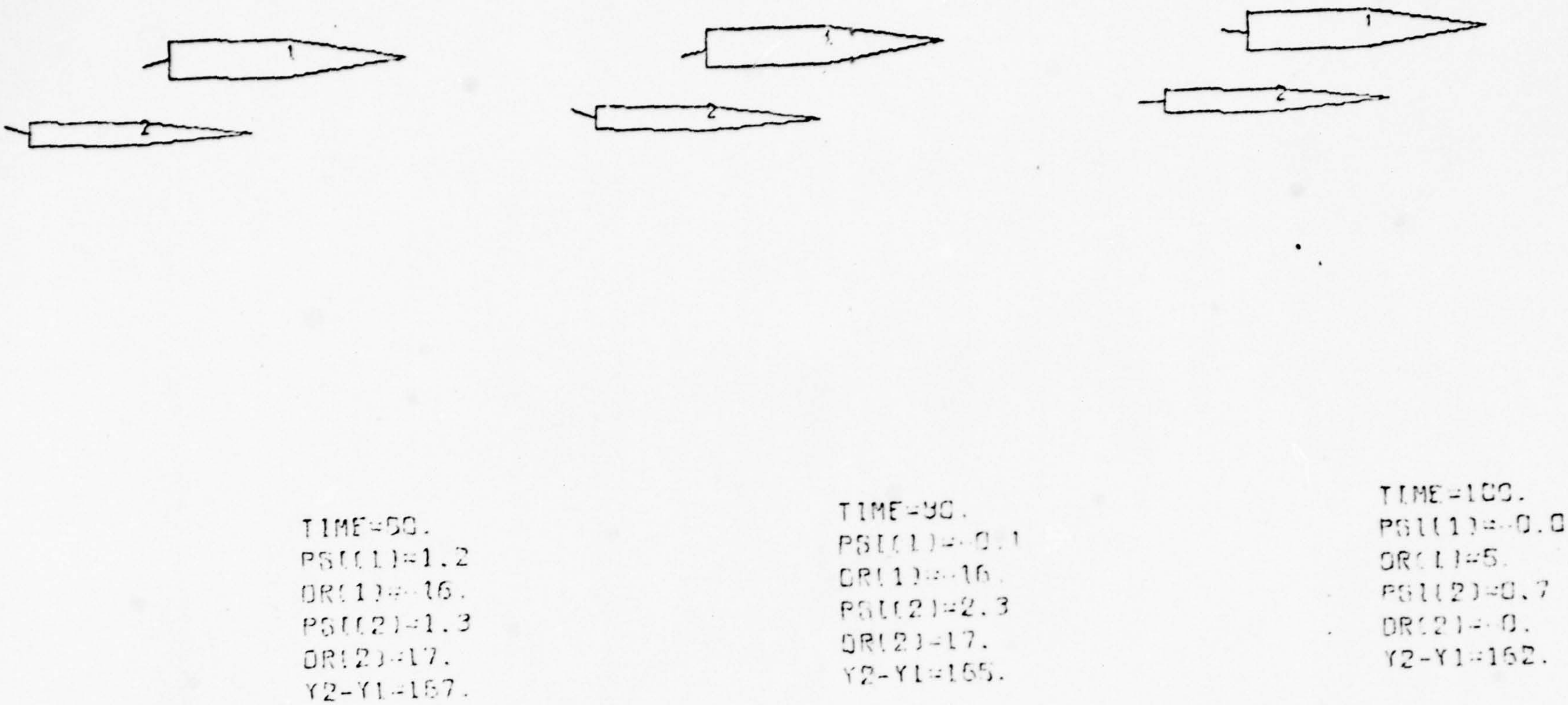
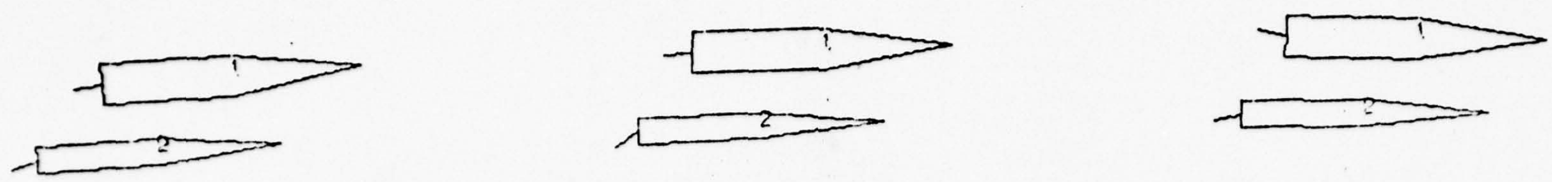


Figure 12 b. Continued.

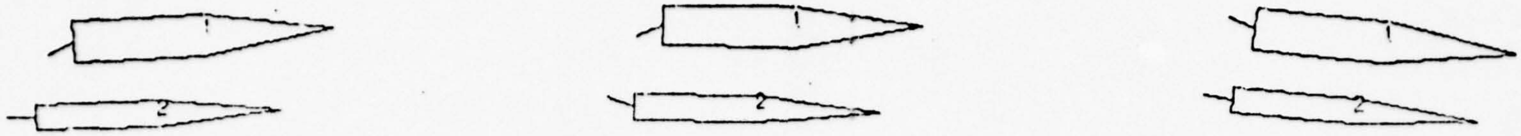


TIME=120.
PSI(1)=-2.9
DR(1)=-5.
PSI(2)=-2.7
DR(2)=-18.
Y2-Y1=162.

TIME=140.
PSI(1)=-0.5
DR(1)=-5.
PSI(2)=-1.2
DR(2)=-30.
Y2-Y1=154.

TIME=160.
PSI(1)=2.2
DR(1)=16.
PSI(2)=-0.8
DR(2)=-12.
Y2-Y1=159.

Figure 12 c. Continued.



TIME=180.
PSI(1)=-3.4
DR(1)=-26.
PSI(2)=-2.2
DR(2)=4.
Y2-Y1=170.

TIME=200.
PSI(1)=0.0
DR(1)=-23.
PSI(2)=0.9
DR(2)=19.
Y2-Y1=173.

TIME=220.
PSI(1)=5.6
DR(1)=19.
PSI(2)=5.1
DR(2)=5.
Y2-Y1=149.

Figure 12 d. Continued.

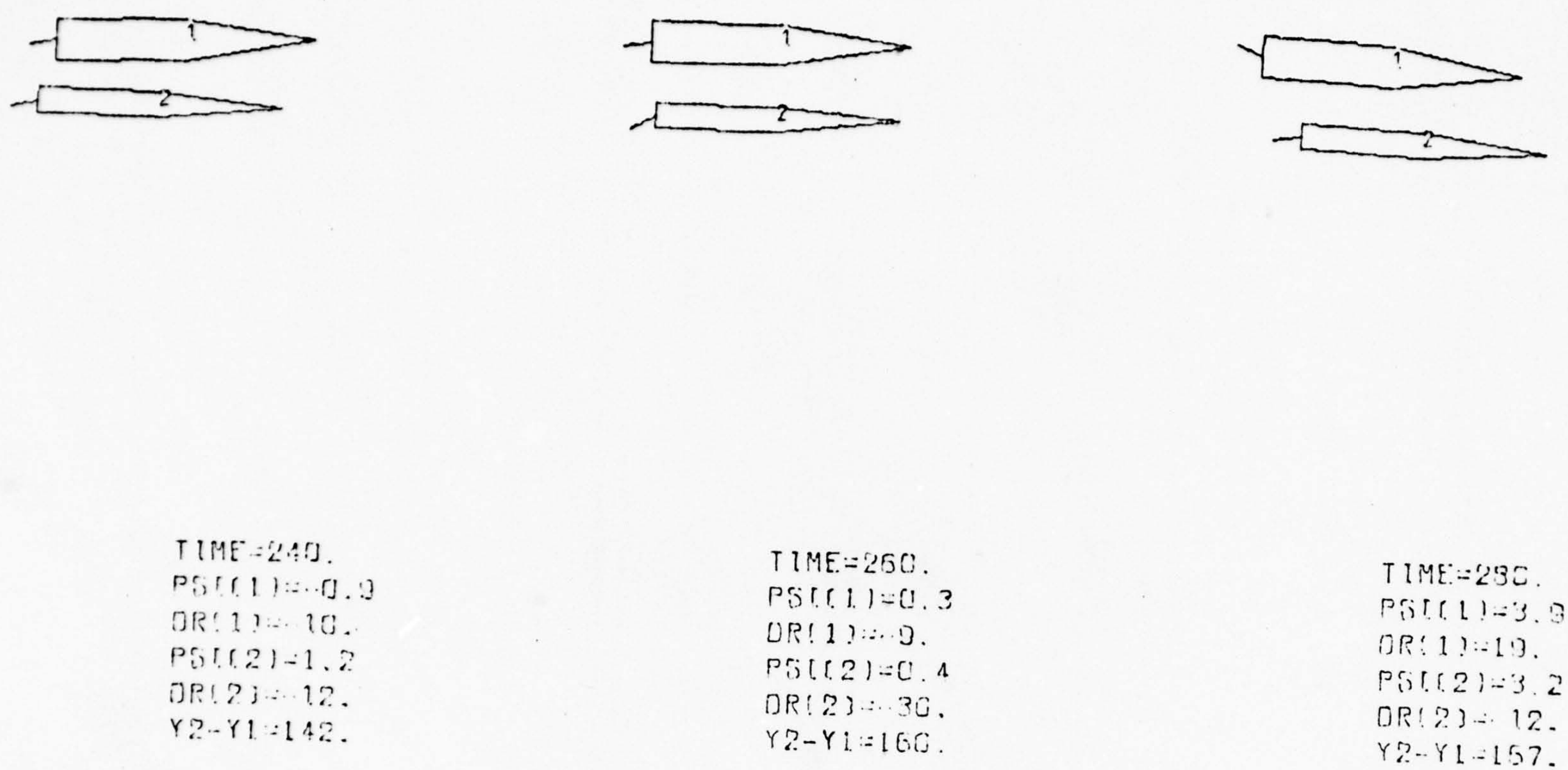


Figure 12 e. Continued.

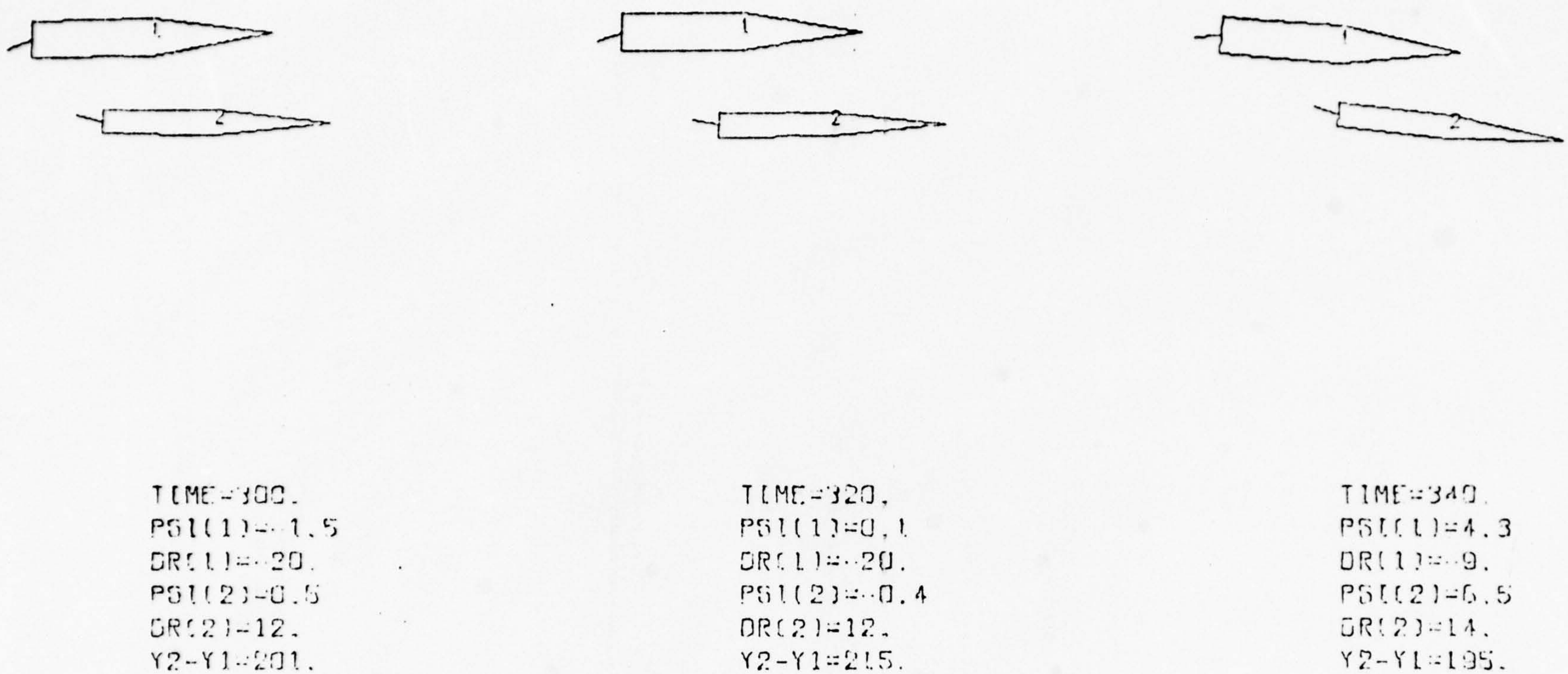
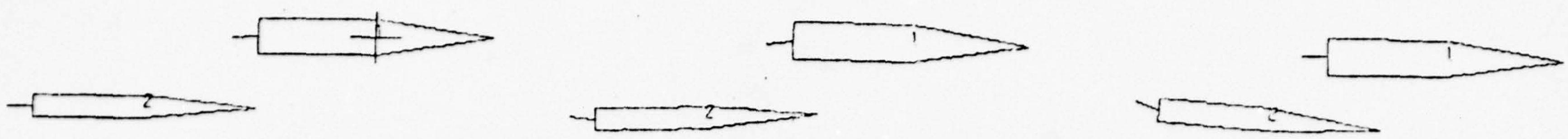


Figure 12 f. Concluded.



TIME=0.
PSI(1)=0.0
DR(1)=-4.
PSI(2)=0.0
DR(2)=0.
Y2-Y1=172.

TIME=20.
PSI(1)=1.0
DR(1)=-10.
PSI(2)=-2.1
DR(2)=10.
Y2-Y1=130.

TIME=40.
PSI(1)=0.5
DR(1)=1.
PSI(2)=4.9
DR(2)=14.
Y2-Y1=148.

Ship 1 = AO-177 Oiler

Ship 2 = Destroyer

Figure 13 a. Underway Replenishment with Increased Rudder Effectiveness.

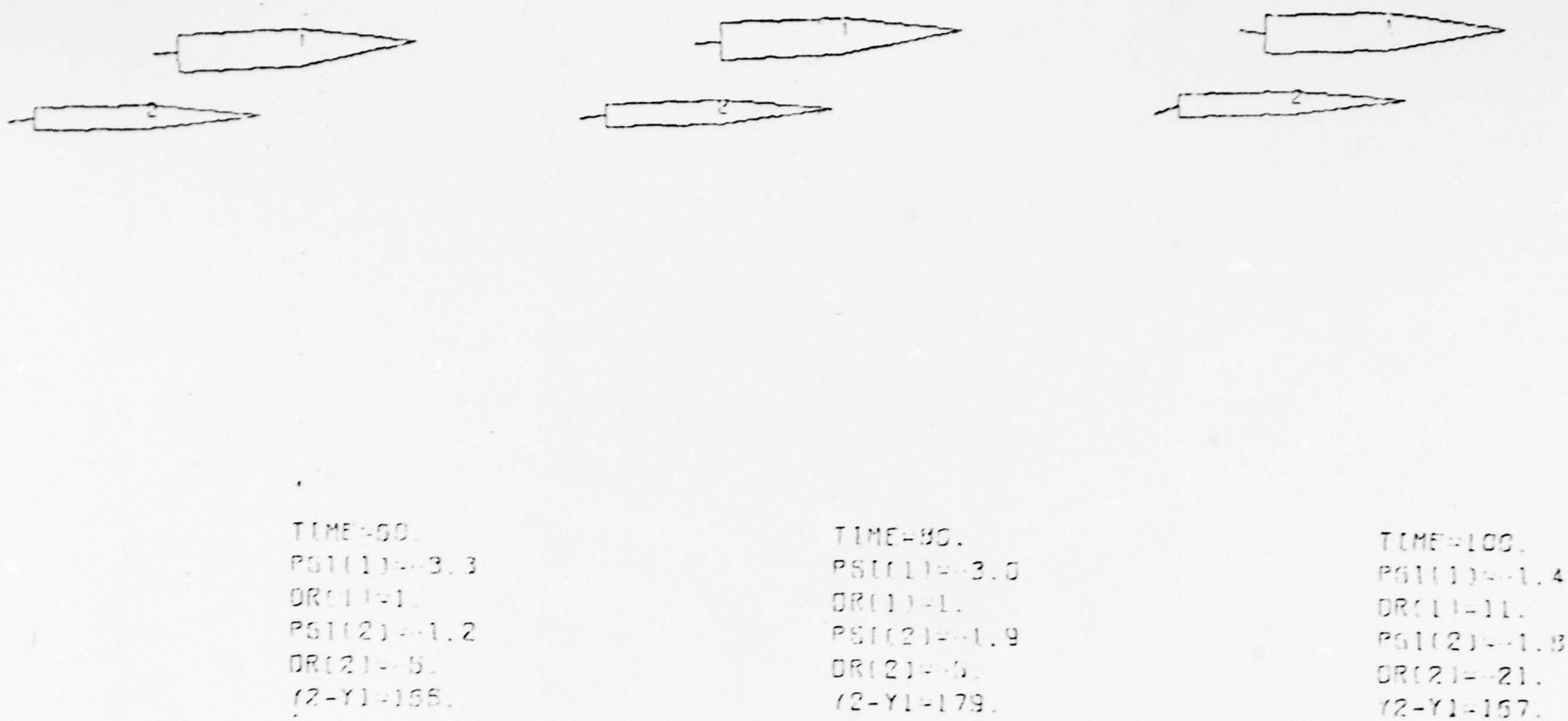
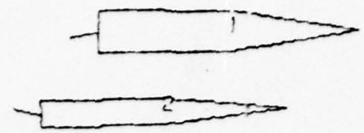


Figure 13 b. Continued.

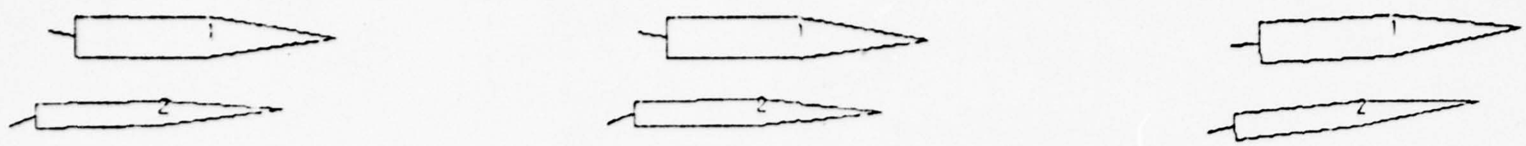


TIME=120.
PSI(1)=-2.4
DR(1)=-10.
PSI(2)=-5.7
DR(2)=-5.
Y2-Y1=185.

TIME=140.
PSI(1)=0.1
DR(1)=-10.
PSI(2)=-1.0
DR(2)=14.
Y2-Y1=156.

TIME=150.
PSI(1)=-2.2
DR(1)=-10.
PSI(2)=4.1
DR(2)=14.
Y2-Y1=149.

Figure 13 c. Continued.

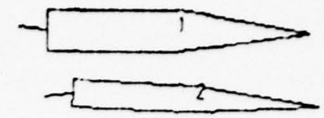


TIME=190.
PSI(1)=0.2
DR(1)=11.
PSI(2)=-1.4
DR(2)=-21.
(2-Y1=163.

TIME=200.
PSI(1)=0.5
DR(1)=11.
PSI(2)=-0.6
DR(2)=-21.
(2-Y1)=159.

TIME=220.
PSI(1)=-3.5
DR(1)=-0.
PSI(2)=-6.1
DR(2)=-5
(2-Y1=168.

Figure 13 d. Continued.

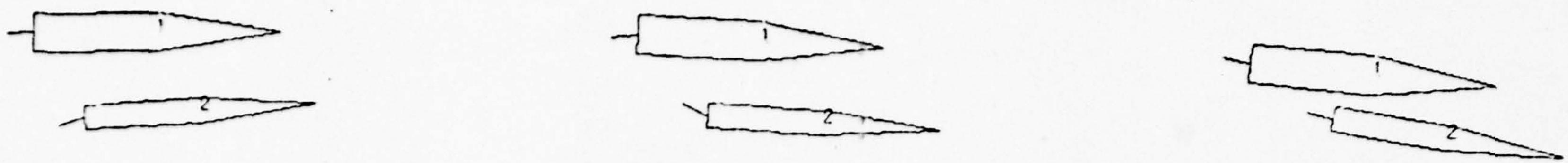


TIME=240.
PSI(1)=-5.9
DR(1)=-32.
PSI(2)=-0.9
DR(2)=30.
Y2-Y1=175

TIME=260.
PSI(1)=2.0
DR(1)=10.
PSI(2)=0.5
DR(2)=-12.
Y2-Y1=151

TIME=280.
PSI(1)=0.5
DR(1)=9.
PSI(2)=2.9
DR(2)=-12.
Y2-Y1=143.

Figure 13 e. Continued.



TIME=300.	TIME=320.	TIME=340.
PSI(1)=-0.3	PSI(1)=3.1	PSI(1)=5.1
DR(1)=-1.	DR(1)=-12.	DR(1)=9.
PSI(2)=-3.9	PSI(2)=3.2	PSI(2)=9.0
DR(2)=-14.	DR(2)=21.	DR(2)=5.
Y2-Y1=176.	Y2-Y1=181.	Y2-Y1=141.

Figure 13 f. Concluded.

TIME=0.
PSI(1)=0.0
DR(1)=-4.
PSI(2)=0.0
DR(2)=0.
Y2-Y1=172.

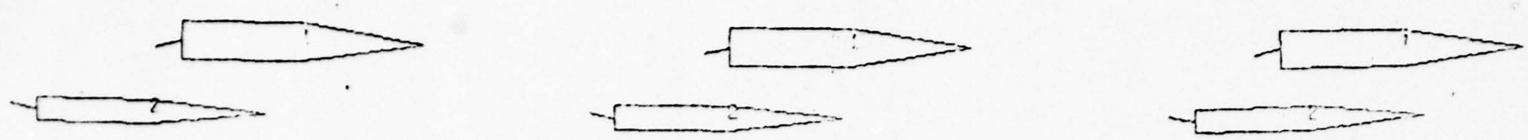
TIME=20.
PSI(1)=1.4
DR(1)=-6.
PSI(2)=-2.0
DR(2)=-4.
Y2-Y1=173

TIME=40.
PSI(1)=1.5
DR(1)=-16.
PSI(2)=-2.2
DR(2)=14.
Y2-Y1=157.

Ship 1 = AO-177 Oiler

Ship 2 = Destroyer

Figure 14 a. Underway Replenishment in Shallow Water with Standard Rudder and Gains.



TIME=60.
PSI(1)=0.8
DR(1)=-15.
PSI(2)=1.4
DR(2)=14.
Y2-Y1=162.

TIME=80.
PSI(1)=-0.3
DR(1)=-15.
PSI(2)=-0.2
DR(2)=12.
Y2-Y1=165.

TIME=100.
PSI(1)=-1.1
DR(1)=-15.
PSI(2)=-1.8
DR(2)=12.
Y2-Y1=154.

Figure 14 b. Continued.

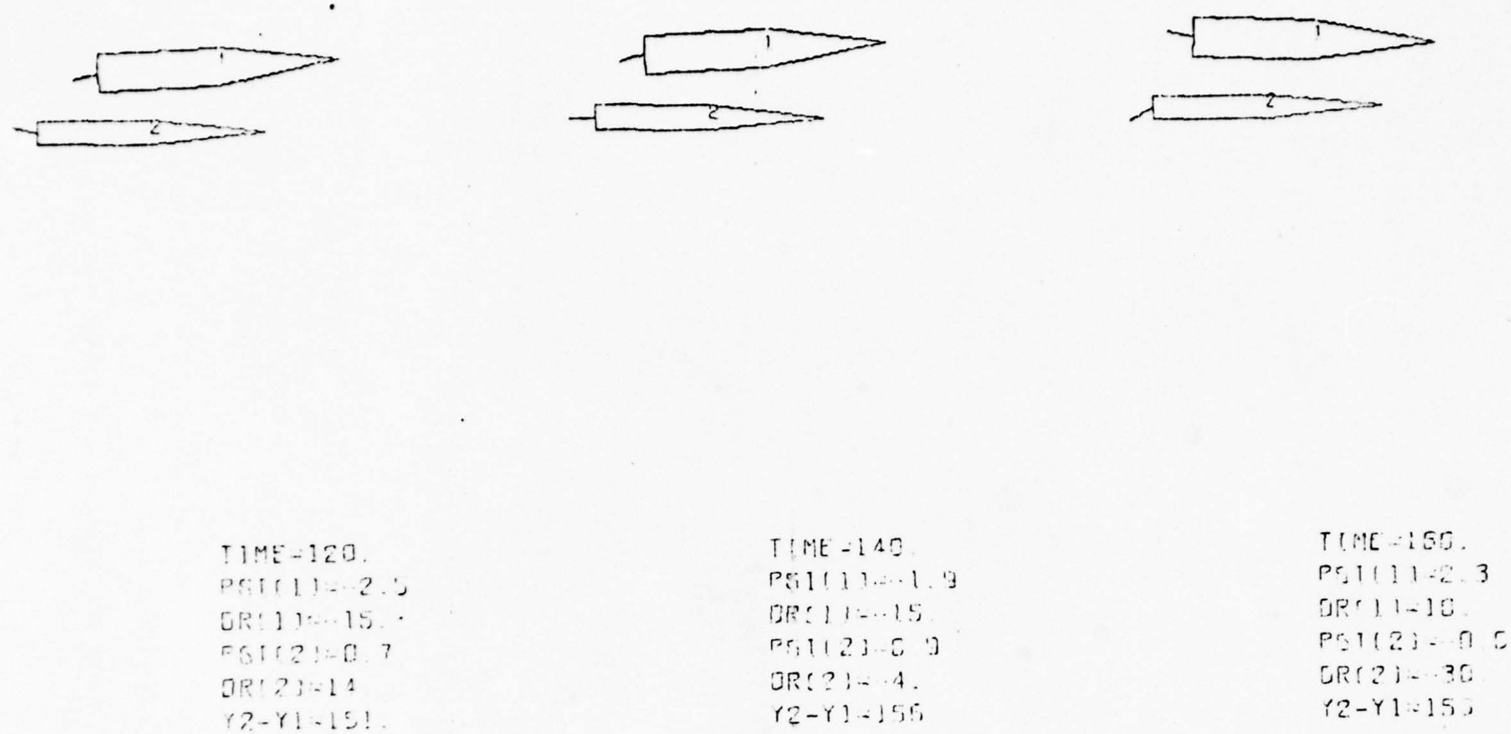


Figure 14 c. Continued.

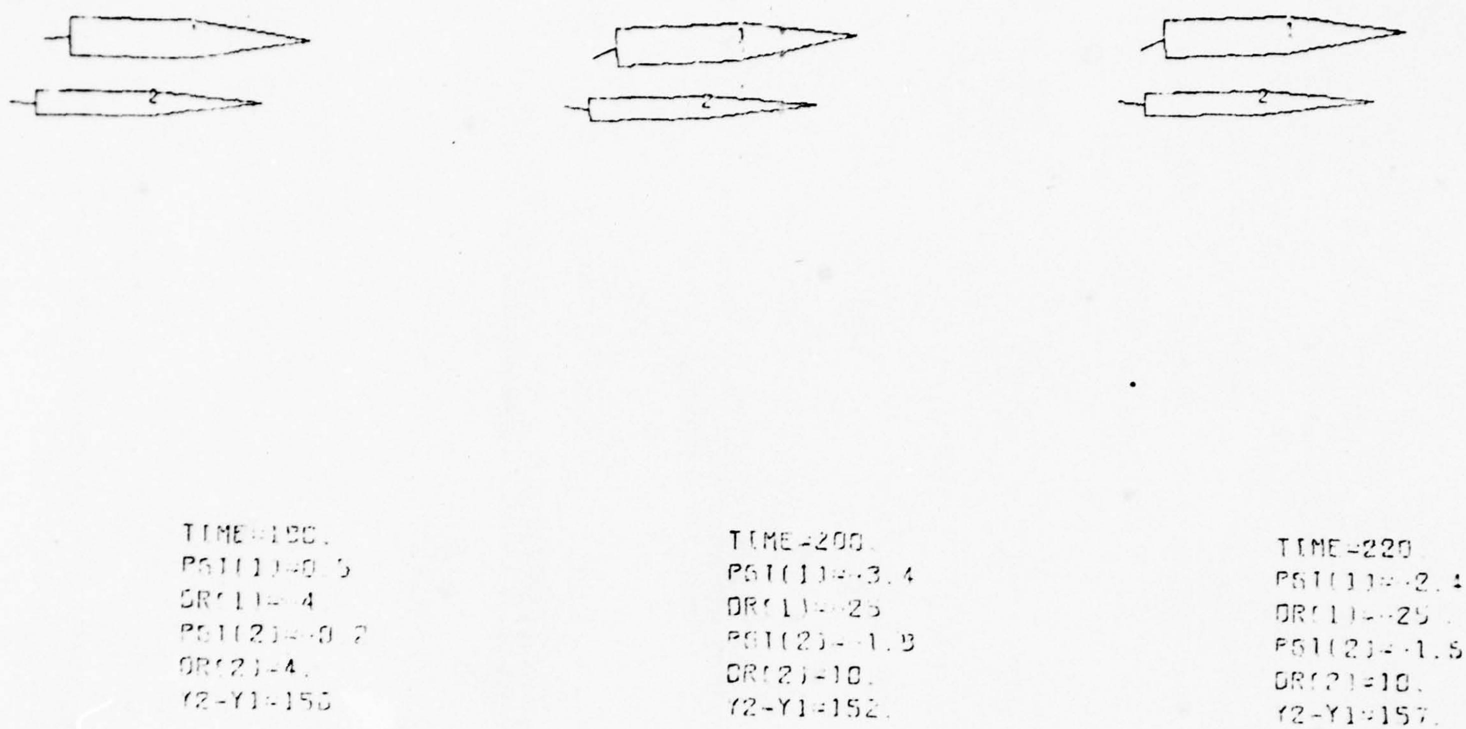
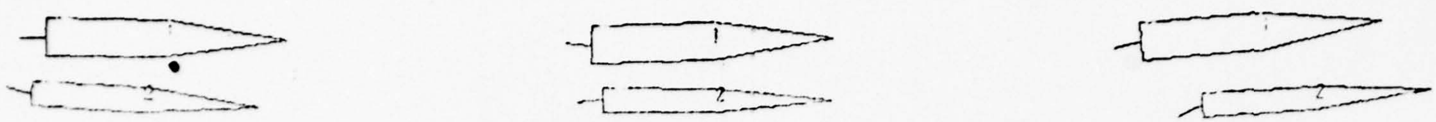


Figure 14 d. Continued.



TIME=240.	TIME=260.	TIME=280.
PSI(1)=1.1	PSI(1)=-1.3	PSI(1)=-4.8
DR(1)=-4.	DR(1)=7.	DR(1)=-11.
PSI(2)=-3.5	PSI(2)=-0.4	PSI(2)=-3.9
DR(2)=14.	DR(2)=-5.	DR(2)=-22.
Y2-Y1=140.	Y2-Y1=134.	Y2-Y1=151.

Figure 14.e. Continued.

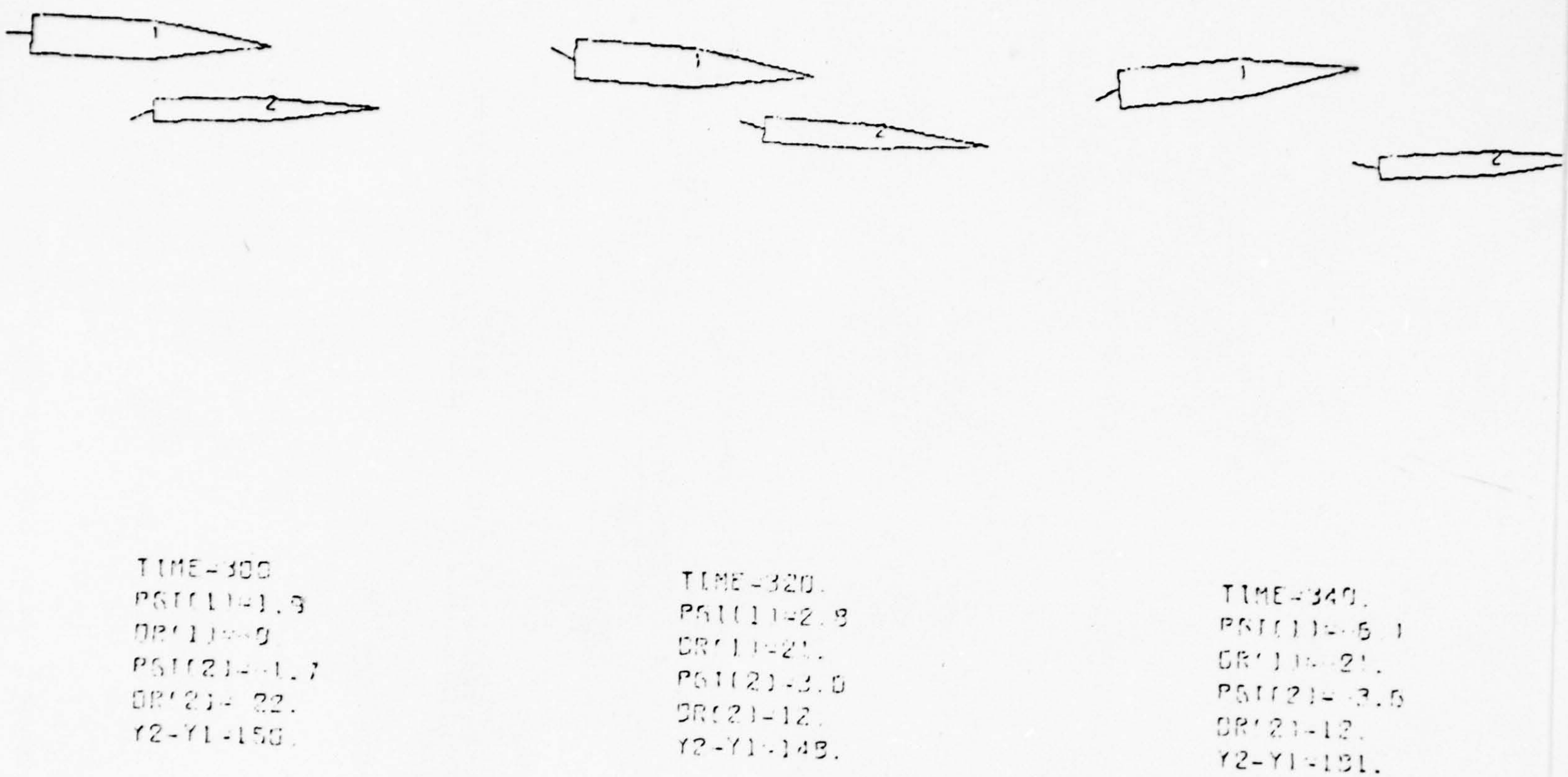


Figure 14 f. Concluded.

REFERENCES

1. Abkowitz, M.A., Ashe, G.M., Fortson, R.M., "Interaction Effects of Ships Operating in Proximity in Deep and Shallow Water", Eleventh Symposium on Naval Hydrodynamics, University College, London, England, March-April 1976.

2. Fortson, R.M., "Interaction Forces Between Ships", MIT Thesis, Ocean Engineering, 1974.

3. Abkowitz, M.A., Stability and Motion Control of Ocean Vehicles, MIT Press, Cambridge, Massachusetts, 1969.

4. Landweber, L. and Yih, C.S., "Forces, Moments and Added Masses for Rankine Bodies", Journal of Fluid Mechanics, Vol. I, September 1956, pp. 319-336.

5. Newton, R.N., "Some Notes on Interaction Effects Between Ships Close Aboard in Deep Water", First Symposium on Ship Maneuverability, David Taylor Model Basin Report No. 1461, Washington, D.C., October 1960, pp. 1-24.

6. Layne, D.E., "The Interaction of Two Vessels in Close Proximity", David W. Taylor Naval Ship Research and Development Center Departmental Report No. SPD 741-01, Bethesda, Maryland, December 1976.

7. Moody, C.G., "The Handling of Ships Through a Widened and Asymmetrically Deepened Section of the Gaillard Cut in the Panama Canal", David Taylor Model Basin Report No. 1705, Washington, D.C., August 1964.

8. Cox, G.G. and Motter, L.E., "Prediction of Standard Maneuvering Characteristics for a Naval Auxiliary Oiler (AO-177 Class)", Naval Ship Research and Development Center Report No. SPD-624-01, Bethesda, Maryland, June 1975.

9. Brown, S.H. and Alvestad, R., "Simulation of Maneuvering Characteristics of a Destroyer Study Ship Using a Modified Nonlinear Model", Journal of Ship Research, Vol. 19, No. 4, December 1975, pp. 254-265.

NOMENCLATURE

A_{22} - lateral added mass coefficient

A_{33} - vertical added mass coefficient

Dlag - rudder control time lag

DR - rudder angle

d_y - horizontal dipole strength

d_{yr} - horizontal dipole strength due to ship yaw rate

d_{yv} - horizontal dipole strength due to ship sway velocity

d_z - vertical dipole strength

e_{ijk} - indicates sign of terms in the moment equation

F - interaction force

Head - ship heading

I_z - polar moment of inertia in yaw

K1C - rudder control gain for yaw

K2R - rudder control gain for yaw rate

K3Y - rudder control gain for lateral separation

K4V - rudder control gain for sway velocity

K5X - speed control gain for longitudinal separation

K6U - speed control gain for speed error

K7A - speed control gain for acceleration

m - mass of the ship

m(x) - source strength

M - interaction moment

MT1 - moment to trim one inch

N	- yaw moment
Pass	- desired lateral ship separation
q'_{02}	- induced lateral flow velocity ignoring d_{yr} and d_{yv}
q_x	- induced longitudinal flow velocity
q_y	- induced lateral flow velocity
q_z	- induced vertical flow velocity
r	- yaw rate
R	- radial distance from the axis
R_b	- radius of the body section representing the ship
Side	- indicates sign in control equation based on which side
Sink	- sinkage due to shallow water effects
t	- time
T	- coordinate transformation matrix
TPI	- tons per inch immersion
Trim	- trim due to shallow water effects
u	- longitudinal velocity
Ucmmd	- velocity commanded by speed control
Ulag	- speed control time lag
v	- sway velocity
x	- longitudinal coordinate or distance
X	- longitudinal force
y	- lateral coordinate or distance
Y	- lateral force
z	- vertical coordinate or distance

Z - vertical force

δ - rudder angle

Δu - change from original speed

ϕ - velocity potential function

ψ - yaw angle

ρ - mass density of water

θ - pitch angle

Subscripts

b - i + 3

I - ship acted on by ship K

int - interaction

K - ship acting on ship I

o - indicated ship has no lateral motion

r - partial derivative with respect to yaw rate

u - partial derivative with respect to surge velocity

v - partial derivative with respect to sway velocity

x - in x-direction or about x-axis

y - in y-direction or about y-axis

z - in z-direction or about z-axis

δ - partial derivative with respect to rudder angle

APPENDIX A

COMPUTER PROGRAM USER'S GUIDE

COMPUTER PROGRAM USER'S GUIDE

A complete listing of the computer program is found in Appendix B. The listing includes the computer program in FORTRAN, the job control language for the MIT Information Processing Center IBM 360 computer as of August 1977, and a sample input for the standard rudder case (Figure 12). The input cards are organized into eleven groups according to function.

Title (one card, format 20A4)
Timing (one card, format 5F10, 2I10)

DELT Integration time step, sec.

BREAK Time for the replenished ship to break away, sec.

ENDTIM Time that simulation ends, sec.

TIMPRN Time of first printing of output, sec.

DTNPRN Number of time steps, DELT, between output prints.

IPRNT Input print option, 0 = print all input, 1 = print all input except coefficients, 2 = no print.

ITERAT Number of iterations to update source and dipole strengths in subroutine INTER, typically 3.

Plot (one card, format 6F10)

SCALDG Scale ratio of the plot.

SRUDL Length of rudder shown on plot, in.

SIZLTR Size of lettering on plot, in.

TIMPLT	Time of first plot, sec.
DTNPLT	Number of time steps, DELT, between plots.
SPCPLT	Space between plots to avoid overlap, in.

The following seven groups are entered in order for the first ship and then for the second ship.

Dimensions (two cards, format 6F10, 5F10, I10)

ALPP	Length of the ship between perpendiculars, ft.
BMLD	Beam of the ship, ft.
DISPL	Displacement of the ship, tons.
CP	Prismatic coefficient.
CM	Midship coefficient.
DRAFT	Draft of the ship, ft.

Card 2

A22	Lateral added mass coefficient.
A33	Vertical added mass coefficient.
TPI	Tons per inch immersion, ton/in.
MT1	Moment to trim one inch, ft-ton/in.
XLCG	Longitudinal center of gravity, ft.
NSTA	Number of stations, max. 21.

Sectional area (3 cards, format 8F10, 8F10, 5F10)

SECAR Sectional area coefficient, A/A_{max} (bow to stern).

Beam (3 cards, format 8F10, 8F10, 5F10)

BEAM Beam coefficient, B/BMLD (bow to stern).

Draft (3 cards, format 8F10, 8F10, 5F10).

RDRAFT Draft coefficient, T/DRAFT (bow to stern).

Coefficients (8 cards, format 6F10, 6F10, 8F10, 8F10, 7F10, 8F10, 8F10, 7F10)

XUUU Partial derivative of X force with respect to u^3.

XUU Partial derivative of X force with respect to u^2.

XU Partial derivative of X force with respect to u.

XVV Partial derivative of X force with respect to v^2.

XVR Partial derivative of X force with respect to v and r.

XVD Partial derivative of X force with respect to v and δ.

Card 2

XRR Partial derivative of X force with respect to r^2.

XRD Partial derivative of X force with respect to r and δ.

XDD Partial derivative of X force with respect to δ^2.

XDDU Partial derivative of X force with respect to δ^2 and u.

XO Constant X force.

XUDOT Added mass coefficient in surge.

Card 3

YDUU Partial derivative of Y force with respect to δ and u^2.

YDU Partial derivative of Y force with respect to δ and u.

YOU Partial derivative of Y force with respect to u.

YVU Partial derivative of Y force with respect to v and u.

YVVV Partial derivative of Y force with respect to v^3.

YVV Partial derivative of Y force with respect to $|v|$ and v.

YV Partial derivative of Y force with respect to v.

YRVV Partial derivative of Y force with respect to v and r^2.

Card 4

YDVV Partial derivative of Y force with respect to δ and v^2.

YRV Partial derivative of Y force with respect to r and v.

YDV Partial derivative of Y force with respect to δ and v.

YVRD Partial derivative of Y force with respect to v, r, δ.

YRRR Partial derivative of Y force with respect to r^3.

YR Partial derivative of Y force with respect to r.

YVRR Partial derivative of Y force with respect to v and r^2.

YDRR Partial derivative of Y force with respect to δ and r^2.

Card 5

YDDD Partial derivative of Y force with respect to δ^3.

YD	Partial derivative of Y force with respect to δ.
YVDD	Partial derivative of Y force with respect to v and δ^2.
YRDD	Partial derivative of Y force with respect to r and δ^2.
YO	Constant Y force.
YVDOT	Added mass in sway.
YRDOT	Added mass in yaw.

Card 6

NDDU	Partial derivative of N moment with respect to δ^2,u.
NDU	Partial derivative of N moment with respect to δ and u.
NOU	Partial derivative of N moment with respect to u.
NVU	Partial derivative of N moment with respect to v and u.
NVVV	Partial derivative of N moment with respect to v^3.
NVV	Partial derivative of N moment with respect to $\|v\|$,v.
NV	Partial derivative of N moment with respect to v.
NRVV	Partial derivative of N moment with respect to r and v^2.

Card 7

NDVV	Partial derivative of N moment with respect to δ,v^2.
NRV	Partial derivative of N moment with respect to r and v.
NDV	Partial derivative of N moment with respect to δ and v.
NVRD	Partial derivative of N moment with respect to v,r,δ
NRRR	Partial derivative of N moment with respect to r^3.
NR	Partial derivative of N moment with respect to r.

NVRR Partial derivative of N moment with respect to v,r^2.

NDRR Partial derivative of N moment with respect to δ,r^2.

Card 8

NDDD Partial derivative of N moment with respect to δ^3.

ND Partial derivative of N moment with respect to δ.

NVDD Partial derivative of N moment with respect to v,δ^2.

NRDD Partial derivative of N moment with respect to r,δ^2.

NO Constant N moment.

NVDOT Added moment of inertia in sway.

NRDOT Added moment of inertia in yaw.

Rudder (2 cards, format 8F10, 1F10)

DRMAX Maximum rudder angle, deg.

DRDOT Rudder turn rate, deg/sec.

DRSENT Minimum change in rudder angle acted on, deg.

CK1C Rudder control gain for yaw, deg/deg.

CK2R Rudder control gain for yaw rate, deg/deg/sec.

CK3Y Rudder control gain for lateral separation, deg/ft.

CK4V Rudder control gain for sway velocity, deg/ft/sec.

DLAG Rudder control lag, sec.

Card 2

DRO Initial rudder angle, deg.

Speed (1 card, format 8F10)

UO	Initial speed, knots.
CK5X	Speed control gain for longitudinal separation, ft/sec/ft.
CK6U	Speed control gain for speed, ft/sec-ft/sec.
CK7U	Speed control gain for acceleration, ft/sec-ft/sec^2.
ULAG	Speed control lag, sec.
UACC	Maximum rate of acceleration of ship, ft/sec^2.
UDEC	Maximum rate of deceleration of ship, ft/sec^2.
USENT	Minimum speed change acted on, knots.

Repeat above 7 card sets for ship 2.

Locations (2 cards, format 7F10, I10, 3F10)

XDIM	Initial longitudinal separation, ft.
YDIM	Initial lateral separation CL to CL, ft.
CI	Initial angle of trailing ship 2, deg.
PASDIS	Commanded lateral separation, ft.
XLDEC	Distance from ship 1 where ship 2 starts decelerating to match the speed of ship 1 for underway replenishment, ft.
DEPTH	Depth of water, ft.
ROW	Mass density of water, lb-sec^2/ft^4.
IPASS	Pass control, 0 = underway replenishment, 1 = steady pass.

Card 2

YCONT Width of relative heading and separation control zone, ft.

HEADBR Commanded heading of ship 2 after BREAK time, deg.

UBREAK Commanded speed of ship 2 after BREAK time, knots.

APPENDIX B

COMPUTER PROGRAM LISTING

```
/*SETUP UNIT=TAPE9,ID=(CALCMP,RING,SAVE,NL),DDNAME=FT09F001
// EXEC FORCLG,LIBRARY='SYS5.PLOT.SUBR',REGION.G=96K
//C.SYSIN DD *,DCB=BLKSIZE=2000
```

PAGE 1

```
C      MAIN PROGRAM                                                               MAIN0001
C                                                                                 MAIN0002
C      THE SHALLOW WATER SHIP TRAJECTORY PROGRAM                                  MAIN0003
C                                                                                 MAIN0004
C      MODEL WITH ADDED PLOT SUBROUTINE DATAPL                           MOD01000 MAIN0005
C      INPUT REVISED TO PRINT INPUT AND SET UP INPUT COMMON BLOCKS       MOD02000 MAIN0006
C      REVISED OPERATING COMMON BLOCKS                                   MOD03000 MAIN0007
C      CROSS-COUPLING AND UNSTEADY INTERACTION FORCES AND MOMENTS ADDED  MOD04000 MAIN0008
C      REVISED RUDDER AND SPEED CONTROLS                                 MOD05000 MAIN0009
C      REVISED HIT SUBROUTINE                                            MOD06000 MAIN0010
C                                                                                 MAIN0011
       REAL NBAR,NINT,MTI                                                MOD03001 MAIN0012
       COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT        MOD02003 MAIN0013
       COMMON/IN2PLT/SCALDG,SRUDL,SIZLTR,TIMPLT,DTNPLT,SPCPLT            MOD02004 MAIN0014
       COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),      MOD02005 MAIN0015
     2 A22(2),A33(2),TPI(2),MTI(2),XLCG(2),NSTA(4)                       MOD02005 MAIN0016
       COMMON/IN4SAC/SECAR(2,21)                                         MOD02006 MAIN0017
       COMMON/IN5BEM/BEAM(2,21)                                          MOD02007 MAIN0018
       COMMON/IN6DRF/RDRAFT(2,21)                                        MOD02008 MAIN0019
       COMMON/IN8RUD/DRMAX(2),DRDOT(2),DRSENT(2),CK1C(2),CK2R(2),CK3Y(2),MOD02010 MAIN0020
     1 CK4V(2),DLAG(2),DRO(2)                                            MOD02010 MAIN0021
       COMMON/IN9SPD/UO(2),CK5X(2),CK6U(2),CK7A(2),ULAG(2),UACC(2),      MOD02011 MAIN0022
     1 UDEC(2),USENT(2)                                                  MOD02011 MAIN0023
       COMMON/INOLOC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MOD02012 MAIN0024
     1 YCONT,HEADBR,UBREAK                                               MOD02012 MAIN0025
       COMMON/OP1TIM/TIME,DELTI,SALPP(2),SBMLD(2),IST                    MOD03002 MAIN0026
       COMMON/OP2CON/PI,PIRO4,DEGRAD,RADDEG,FND(2),FPSKTS                MOD03003 MAIN0027
       COMMON/OP3DIM/X1(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21),         MOD03004 MAIN0028
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4)          MOD03004 MAIN0029
       COMMON/OP4SMD/SM(4,21),SUM(4,21),SDY(4,21),SUDY(4,21),SDYV(4,21), MOD03005 MAIN0030
     1 SDYR(4,21),SDZ(4,21),SUDZ(4,21)                                   MOD03005 MAIN0031
       COMMON/OP5VEL/UOA(2,21),UOY(2,21),UOZ(2,21)                       MOD03006 MAIN0032
       COMMON/OP6FCR/XBAR(2),YBAR(2),NBAR(2),XINT(2),YINT(2),NINT(2),    MOD03007 MAIN0033
     1 FXT(2),FYT(2),FZT(2),RXT(2),RYT(2),RZT(2)                         MOD03007 MAIN0034
       COMMON/OP7ACC/UDDOT(2),UODOT(2),VDDOT(2),VODOT(2),RDDOT(2)        MOD03008 MAIN0035
       COMMON/OP8RUD/DR(2),DRCAPT(2)                                     MOD03009 MAIN0036
```

```
      COMMON/OP9SPD/UDIM(2),DELU(2),UDDIM(2),V(2),VDIM(2),VDDIM(2),R(2),MOD03010 MAIN0037
     1 RDIM(2),UCAPI(2)                                                 MOD03010 MAIN0038
      COMMON/OPOLCC/XREL(2),YREL(2),XCLEAR,HEAD(2),LX                   MOD03011 MAIN0039
      PI=3.141593                                                                MAIN0040
      DEGRAD=.01745329                                                           MAIN0041
      RADDEG=57.29578                                                            MAIN0042
      FPSKTS=1.0/1.689                                                           MAIN0043
      CALL INPUT                                                                 MAIN0044
      PIRO4=-4.0*PI*ROW/2.                                              MOD04005 MAIN0045
      DO 100 J=1,2                                                               MAIN0046
      FND(J)=.5*RCW*ALPP(J)*ALPP(J)                                              MAIN0047
      UDIM(J)=UO(J)                                                              MAIN0048
      DELU(J)=0.                                                                 MAIN0049
      V(J)=0.                                                                    MAIN0050
      VDIM(J)=0.                                                                 MAIN0051
      R(J)=0.                                                                    MAIN0052
      RDIM(J)=0.                                                                 MAIN0053
      UDDOT(J)=0.                                                                MAIN0054
      UDDDI(J)=0.                                                                MAIN0055
      VDDOT(J)=0.                                                                MAIN0056
      VDDDI(J)=0.                                                                MAIN0057
      RDDOT(J)=0.                                                                MAIN0058
      SINK(J)=0.                                                                 MAIN0059
      DR(J)=DRO(J)                                                               MAIN0060
      XINT(J)=0.                                                                 MAIN0061
      YINT(J)=0.                                                                 MAIN0062
      NINT(J)=0.                                                                 MAIN0063
      XBAR(J)=0.                                                                 MAIN0064
      YBAR(J)=0.                                                                 MAIN0065
      NBAR(J)=0.                                                                 MAIN0066
      L=J+2                                                                      MAIN0067
      TRIM(J)=0.                                                                 MAIN0068
      TRIM(L)=0.                                                                 MAIN0069
      ZDIM(J)= DEPTH                                                             MAIN0070
      ZDIM(L)=-DEPTH                                                             MAIN0071
  100 CONTINUE                                                                   MAIN0072
```

```
      IST=0
      XDIM(1)=0.                                                        MAIN0073
      XDIM(3)=0.                                                        MAIN0074
      XDIM(4)=XDIM(2)                                                   MAIN0075
      YDIM(1)=0.                                                        MAIN0076
      YDIM(3)=0.                                                        MAIN0077
      YDIM(4)=YDIM(2)                                                   MAIN0078
      CI(1)=0.                                                          MAIN0079
      CI(3)=0.                                                          MAIN0080
      CI(4)=CI(2)                                                       MAIN0081
      XCLEAR=.5*(ALPP(1)+ALPP(2))                              MOD05084 MAIN0082
      HEAD(1)=CI(1)                                            MOD05085 MAIN0083
      HEAD(2)=CI(2)                                            MOD05086 MAIN0084
      PASDIS=PASDIS+.5*(BMLD(1)+BMLD(2))                       MOD05087 MAIN0085
      LX=0                                                     MOD05088 MAIN0086
      YCONT=YCONT+(BMLD(1)+BMLD(2))*.5                                  MAIN0087
      TIME=0.                                                           MAIN0088
      DELTI=0.0                                                         MAIN0089
      IF(ITERAT .LT. 1) ITERAT=1                                        MAIN0090
      DO 140 I=1,2                                                      MAIN0091
      IN=NSTA(I)                                                        MAIN0092
      IP=IN-1                                                           MAIN0093
      DX(I)=ALPP(I)/IP                                                  MAIN0094
      DO 110 J=1,IN                                                     MAIN0095
      SECAR(I,J)= SECAR(I,J)*BMLD(I)*DRAFT(I)*CM(I)                     MAIN0096
      BEAM(I,J)=BEAM(I,J)*BMLD(I)*.5                                    MAIN0097
      RDRAFT(I,J)=RDRAFT(I,J)*DRAFT(I)                                  MAIN0098
      RAD(I,J)=SQRT(2.*SECAR(I,J)/PI)                                   MAIN0099
      RY2(I,J)=RAD(I,J)                                                 MAIN0100
      RZ3(I,J)=RAD(I,J)                                                 MAIN0101
      RYZ(I,J)=RAD(I,J)                                                 MAIN0102
  110 CONTINUE                                                          MAIN0103
      DLPPI=2.*DX(I)                                                    MAIN0104
      DO 120 K=2,IP                                                     MAIN0105
      IA=K+1                                                            MAIN0106
      IB=K-1                                                            MAIN0107
      DRYZDX(I,K)=(RYZ(I,IA)-RYZ(I,IB))/DLPPI                           MAIN0108
```

```
  120 CONTINUE                                                              MAIN0109
      DRYZDX(I,1)=(RYZ(I,2)-RYZ(I,1))/DX(I)                                 MAIN0110
      DRYZDX(I,IN)=(RYZ(I,IN)-RYZ(I,IP))/DX(I)                              MAIN0111
      J=I+2                                                                 MAIN0112
      DX(J)=DX(I)                                                           MAIN0113
      NSTA(J)=NSTA(I)                                                       MAIN0114
      XINC=.5*ALPP(I)+DX(I)                                                 MAIN0115
      WRITE(6,800) I                                                        MAIN0116
      DO 130 L=1,IN                                                         MAIN0117
      AL=L                                                                  MAIN0118
      XI(I,L)=XINC-AL*DX(I)                                                 MAIN0119
      WRITE(6,900) L,BEAM(I,L),RDRAFT(I,L),SECAR(I,L),RAD(I,L),RY2(I,L),   MAIN0120
     1 RZ3(I,L),RYZ(I,L),DRYZDX(I,L),XI(I,L)                                MAIN0121
      SM(I,L)=0.0                                                           MAIN0122
      SDY(I,L)=0.                                                           MAIN0123
      SDZ(I,L)=0.                                                           MAIN0124
      SDYV(I,L)=0.0                                                MOD04007 MAIN0125
      SDYR(I,L)=0.0                                                MOD04008 MAIN0126
C     SDZW(I,L)=0.0                                                MOD04010 MAIN0127
C     SDZO(I,L)=0.0                                                MOD04009 MAIN0128
      UOY(I,L)=0.0                                                 MOD04012 MAIN0129
C     UOZ(I,L)=0.0                                                 MOD04013 MAIN0130
      XI(J,L)=XI(I,L)                                                       MAIN0131
  130 CONTINUE                                                              MAIN0132
C     SCALE LENGTHS FOR PLOT                                                MAIN0133
      SALPP(I)=ALPP(I)/SCALDG                                               MAIN0134
      SBMLD(I)=BMLD(I)/SCALDG                                               MAIN0135
  140 CONTINUE                                                              MAIN0136
      WRITE(6,1000)                                                         MAIN0137
  150 CONTINUE                                                              MAIN0138
      CALL HIT                                                              MAIN0139
      IF(TIME .GE. ENDTIM) GO TO 200                                        MAIN0140
      IF (TIME .NE. TIMPLT) GO TO 180                              MOD03035 MAIN0141
      CALL DATAPL                                                  MOD01000 MAIN0142
      TIMPLT=TIMPLT+DTNPLT*DELT                                    MOD03036 MAIN0143
  180 CONTINUE                                                     MOD03037 MAIN0144
                                                                        PAGE    5
```

```
      CALL INTER                                                        MAIN0145
      DELTI=1.0/DELT                                                    MAIN0146
      CALL DIFEQ                                                        MAIN0147
      TIME=TIME+DELT                                                    MAIN0148
      GO TO 150                                                         MAIN0149
  200 CONTINUE                                                          MAIN0150
C     PLOT FINAL POSITION WHEN TIME=ENDTIM                              MAIN0151
      IF(TIMPL .GT. 0.0) CALL DATAPL                                    MAIN0152
      STOP                                                              MAIN0153
  800 FORMAT(5H0SHIP,I3,2X,4HNSTA,2X,9HHALF BEAM,4X,5HDRAFT,4X,         MAIN0154
     1 9HSECT AREA,2X,8HSECT RAD,3X,9HY AVG RAD,2X,9HZ AVG RAD,3X,      MAIN0155
     2 7HAVG RAD,4X,6HDRYZDX,7X,2HX1)                                   MAIN0156
  900 FORMAT(11X,I2,1X,9(1X,F10.4))                                     MAIN0157
 1000 FORMAT(1H1)                                                       MAIN0158
      END                                                               MAIN0159
```

```
      SUBROUTINE INPUT                                                   INPT0001
      REAL NDUU,NDU,NOU,NVU,NVVV,NVV,NV,NRVV,NDVV,NRV,NDV,NVRD,NRRR,NR, MOD02001 INPT0002
     1 NVRR,NDRR,NDDD,ND,NVDD,NRDD,NO,NVDOT,NRDOT,MT1                    MOD02001 INPT0003
      REAL*4 TITLE(20),DAYTIM(5)                                         MOD02002 INPT0004
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT         MOD02003 INPT0005
      COMMON/IN2PLT/SCALDG,SRUDL,SIZLTR,TIMPLT,DTNPLT,SPCPLT             MOD02004 INPT0006
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),       MOD02005 INPT0007
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)                       MOD02005 INPT0008
      COMMON/IN4SAC/SECAR(2,21)                                          MOD02006 INPT0009
      COMMON/IN5BEM/BEAM(2,21)                                           MOD02007 INPT0010
      COMMON/IN6DRF/RDRAFT(2,21)                                         MOD02008 INPT0011
      COMMON/IN7CCF/XUUU(2),XUU(2),XU(2),XVV(2),XVR(2),XVD(2),          .MOD02009 INPT0012
     2 XRR(2),XRD(2),XDD(2),XDDU(2),XO(2),XUDOT(2),                      MOD02009 INPT0013
     3 YDUU(2),YDU(2),YOU(2),YVU(2),YVVV(2),YVV(2),YV(2),YRVV(2),        MOD02009 INPT0014
     4 YDVV(2),YRV(2),YDV(2),YVRD(2),YRRR(2),YR(2),YVRR(2),YDRR(2),      MOD02009 INPT0015
     5 YDDU(2),YD(2),YVDD(2),YRDD(2),YO(2),YVDOT(2),YRDOT(2),            MOD02009 INPT0016
     6 NDUU(2),NDU(2),NOU(2),NVU(2),NVVV(2),NVV(2),NV(2),NRVV(2),        MOD02009 INPT0017
     7 NDVV(2),NRV(2),NDV(2),NVRD(2),NRRR(2),NR(2),NVRR(2),NDRR(2),      MOD02009 INPT0018
     8 NDDD(2),ND(2),NVDD(2),NRDD(2),NO(2),NVDOT(2),NRDOT(2)             MOD02009 INPT0019
      COMMON/IN8RUD/DRMAX(2),DRDOT(2),DRSENT(2),CK1C(2),CK2R(2),CK3Y(2),MOD02010 INPT0020
     1 CK4V(2),DLAG(2),DRO(2)                                            MOD02010 INPT0021
      COMMON/IN9SPD/UO(2),CK5X(2),CK6U(2),CK7A(2),ULAG(2),UACC(2),       MOD02011 INPT0022
     1 UDEC(2),USENT(2)                                                  MOD02011 INPT0023
      COMMON/INOLCC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS,  MOD02012 INPT0024
     1 YCONT,HEADBR,UBREAK                                               MOD02012 INPT0025
      COMMON/OP2CON/PI,PIRO4,DEGRAD,RADDEG,FND(2),FPSKTS                 MOD03003 INPT0026
      CALL WHEN(DAYTIM)                                                  MOD02013 INPT0027
      READ(5,800) TITLE                                                  MOD02014 INPT0028
      READ(5,810) DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT           MOD02015 INPT0029
      READ(5,820) SCALDG,SRUDL,SIZLTR,TIMPLT,DTNPLT,SPCPLT               MOD02016 INPT0030
      DO 100 I=1,2                                                       MOD02017 INPT0031
      READ(5,820) ALPP(I),BMLD(I),DISPL(I),CP(I),CM(I),DRAFT(I)          MOD02018 INPT0032
      READ(5,810) A22(I),A33(I),TPI(I),MT1(I),XLCG(I),NSTA(I)            MOD02019 INPT0033
      NSTAI=NSTA(I)                                                      MOD02020 INPT0034
      READ(5,820) (SECAR(I,J),J=1,NSTAI)                                 MOD02021 INPT0035
      READ(5,820) (BEAM(I,J),J=1,NSTAI)                                  MOD02022 INPT0036
                                                                             PAGE    7
```

```
      READ(5,820) (RDRAFT(I,J),J=1,NSTAI)                                MOD02023 INPT0037
      READ(5,820) XUUU(I),XUU(I),XU(I),XVV(I),XVR(I),XVD(I)              MOD02024 INPT0038
      READ(5,820) XRR(I),XRD(I),XDD(I),XDDU(I),XO(I),XUDOT(I)            MOD02025 INPT0039
      READ(5,820) YDUU(I),YDU(I),YOU(I),YVU(I),YVVV(I),YVV(I),YV(I),     MOD02026 INPT0040
     1 YRVV(I)                                                           MOD02026 INPT0041
      READ(5,820) YDVV(I),YRV(I),YDV(I),YVRD(I),YRRR(I),YR(I),YVRR(I),   MOD02027 INPT0042
     1 YDRR(I)                                                           MOD02027 INPT0043
      READ(5,820) YDDD(I),YD(I),YVDD(I),YRDD(I),YO(I),YVDOT(I),YRDOT(I) MOD02028 INPT0044
      READ(5,820) NDUU(I),NDU(I),NOU(I),NVU(I),NVVV(I),NVV(I),NV(I),     MOD02029 INPT0045
     1 NRVV(I)                                                           MOD02029 INPT0046
      READ(5,820) NDVV(I),NRV(I),NDV(I),NVRD(I),NRRR(I),NR(I),NVRR(I),   MOD02030 INPT0047
     1 NDRR(I)                                                           MOD02030 INPT0048
      READ(5,820) NDDD(I),ND(I),NVDD(I),NRDD(I),NO(I),NVDOT(I),NRDOT(I) MOD02031 INPT0049
      READ(5,820) DRMAX(I),DRDOT(I),DRSENT(I),CK1C(I),CK2R(I),CK3Y(I),   MOD02032 INPT0050
     1 CK4V(I),DLAG(I),DRO(I)                                            MOD02032 INPT0051
      READ(5,820) UO(I),CK5X(I),CK6U(I),CK7A(I),ULAG(I),UACC(I),UDEC(I) MOD02033 INPT0052
     1,USENT(I)                                                          MOD02033 INPT0053
  100 CONTINUE                                                           MOD02034 INPT0054
      READ(5,830) XDIM(2),YDIM(2),CI(2),PASDIS,XLDEC,DEPTH,ROW,IPASS,    MOD02035 INPT0055
     1 YCONT,HEADBR,UBREAK                                               MOD02035 INPT0056
      IF(IPRNT .EQ. 2) GO TO 250                                         MOD02036 INPT0057
      WRITE(6,900) TITLE,DAYTIM                                          MOD02037 INPT0058
      WRITE(6,910) DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT,         MOD02038 INPT0059
     1 SCALDG,SRUDL,SIZLTR,TIMPLT,DTNPLT,SPCPLT                          MOD02038 INPT0060
      DO 200 I=1,2                                                       MOD02039 INPT0061
      WRITE(6,930) I,ALPP(I),BMLD(I),DISPL(I),CP(I),CM(I),DRAFT(I),      MOD02040 INPT0062
     2 A22(I),A33(I),TPI(I),MT1(I),XLCO(I),NSTA(I)                       MOD02040 INPT0063
      NSTAI=NSTA(I)                                                      MOD02041 INPT0064
      WRITE(6,950) (J,SECAR(I,J),BEAM(I,J),RDRAFT(I,J),J=1,NSTAI)        MOD02042 INPT0065
      IF(IPRNT .EQ. 1) GO TO 150                                         MOD02043 INPT0066
      WRITE(6,971) XUUU(I),XUU(I),XU(I),XVV(I),XVR(I),XVD(I),            MOD02044 INPT0067
     1 XRR(I),XRD(I),XDD(I),XDDU(I),XO(I),XUDOT(I)                       MOD02044 INPT0068
      WRITE(6,973) YDUU(I),YDU(I),YOU(I),YVU(I),YVVV(I),YVV(I),YV(I),    MOD02045 INPT0069
     1 YRVV(I),YDVV(I),YRV(I),YDV(I),YVRD(I)                             MOD02045 INPT0070
      WRITE(6,974) YRRR(I),YR(I),YVRR(I),YDRR(I),YDDD(I),YD(I),YVDD(I),  MOD02046 INPT0071
     1 YRDD(I),YO(I),YVDOT(I),YRDOT(I)                                   MOD02046 INPT0072
```

```
      WRITE(6,976) NDUU(I),NDU(I),NOU(I),NVU(I),NVVV(I),NVV(I),NV(I),    MOD02047 INPT0073
     1 NRVV(I),NDVV(I),NRV(I),NDV(I),NVRD(I)                             MOD02047 INPT0074
      WRITE(6,977) NRRR(I),NR(I),NVRR(I),NDRR(I),NDDD(I),ND(I),NVDD(I),  MOD02048 INPT0075
     1 NRDD(I),NO(I),NVDCT(I),NRDCT(I)                                   MOD02048 INPT0076
  150 CONTINUE                                                           MOD02049 INPT0077
      WRITE(6,980) DRMAX(I),DRDOT(I),DRSENT(I),CK1C(I),CK2R(I),CK3Y(I),  MOD02050 INPT0078
     1 CK4V(I),DLAG(I),DRO(I)                                            MOD02050 INPT0079
      WRITE(6,990) UO(I),CK5X(I),CK6U(I),CK7A(I),ULAG(I),UACC(I),UDEC(I)MOD02051 INPT0080
     1,USENT(I)                                                          MOD02051 INPT0081
  200 CONTINUE                                                           MOD02052 INPT0082
      WRITE(6,1000) XDIM(2),YDIM(2),CI(2),PASDIS,XLDEC,DEPTH,ROW,IPASS,  MOD02053 INPT0083
     1 YCONT,HEADBR,UBREAK                                               MOD02053 INPT0084
  250 CONTINUE                                                           MOD02054 INPT0085
      DO 300 I=1,2                                                       MOD02055 INPT0086
      TPI(I)=TPI(I)*2240.*12.                                            MOD02055 INPT0087
      MTI(I)=MTI(I)*2240.*12.                                            MOD02056 INPT0088
      DRMAX(I)=DRMAX(I)*DEGRAD                                           MOD02056 INPT0089
      DRDOT(I)=DRDOT(I)*DEGRAD                                           MOD02057 INPT0090
      DRSENT(I)=DRSENT(I)*DEGRAD                                         MOD02058 INPT0091
      CK3Y(I)=CK3Y(I)*DEGRAD                                             MOD02059 INPT0092
      CK4V(I)=CK4V(I)*DEGRAD                                             MOD02060 INPT0093
      DRO(I)=DRO(I)*DEGRAD                                               MOD02060 INPT0094
      UO(I)=UO(I)*1.689                                                  MOD02061 INPT0095
      CI(2)=CI(2)*DEGRAD                                                 MOD02062 INPT0096
      IF(UDEC(I) .GT. 0.0) UDEC(I)=-UDEC(I)                              MOD02062 INPT0097
  300 CONTINUE                                                           MOD02063 INPT0098
      HEADBR=HEADBR*DEGRAD                                               MOD02063 INPT0099
      UBREAK=UBREAK*1.689                                                MOD02064 INPT0100
      WRITE(6,900) TITLE,DAYTIM                                          MOD02064 INPT0101
      WRITE(6,1010) (I,ALPP(I),BMLD(I),DISPL(I),CP(I),I=1,2)             MOD02065 INPT0102
      WRITE(6,1020) PASDIS,DEPTH                                         MOD02066 INPT0103
      RETURN                                                                      INPT0104
  800 FORMAT(20A4)                                                       MOD02067 INPT0105
  810 FORMAT(5F10.5,2I10)                                                MOD02068 INPT0106
  820 FORMAT(8F10.5)                                                     MOD02069 INPT0107
  830 FORMAT(7F10.5,I10)                                                 MOD02070 INPT0108
```

```
900 FORMAT(1H1,15X,81HTRAJECTORIES AND TOTAL FORCES OF TWO SHIPS INVOLMODO2071 INPT0109
   1VED IN CLOSE PROXIMITY OPERATIONS.//,16X,20A4,3X,6HDATE: ,2A4,2X, MODO2071 INPT0110
   2 6HTIME: ,3A4,/)                                                  MODO2071 INPT0111
910 FORMAT(1H0,4X,7HDELTIME,2X,9HBREAKTIME,2X,7HENDTIME,2X,9HPRINTTIMEMODO2072 INPT0112
   1,2X,8HDELTPRNT,3X,6HIPRINT,2X,9HITERATION,1X,9HSCALEPLOT,2X,      MODO2072 INPT0113
   2 7HRUDRLEN,2X,8HSIZELETR,2X,8HPLOTTIME,2X,8HDELTPLOT,2X,          MODO2072 INPT0114
   3 9HSPACEPLOT,/,3X,5(1X,F9.2),1X,I6,4X,I6,3X,6(1X,F9.4))           MODO2072 INPT0115
930 FORMAT(16H0 SHIP LENGTH PP,2X,8HBEAM MLD,1X,9HDISPL TON,1X,       MODO2073 INPT0116
   1 9HPRISMATIC,2X,7HMIDSHIP,4X,5HDRAFT,3X,9HLATADDMAS,1X,9HVRTADDMASMODO2073 INPT0117
   2,2X,8HTONPERIN,1X,9HMOMTRM1IN,2X,7HLONG CG,4X,6HNO STA,/,4X,I1,1X,MODO2073 INPT0118
   3 3(1X,F9.2),5(1X,F9.4),2(1X,F9.1),1X,F9.3,1X,I7)                 MODO2073 INPT0119
950 FORMAT(1H0,6X,4HNSTA,2X,9HSECT AREA,4X,4HBEAM,5X,5HDRAFT,/,(8X,I2,MODO2074 INPT0120
   1 2X,3(1X,F9.6)))                                                  MODO2074 INPT0121
971 FORMAT(1H0,9X,4HXUUU,6X,3HXUU,8X,2HXU,7X,3HXVV,7X,3HXVR,7X,3HXVD, MODO2075 INPT0122
   1 7X,3HXRR,7X,3HXRD,7X,3HXDD,7X,4HXDDU,7X,2HX0,6X,5HXUDOT,/,6X,    MODO2075 INPT0123
   2 12(1X,F9.2))                                                     MODO2075 INPT0124
973 FORMAT(1H0,9X,4HYDUU,6X,3HYDU,7X,3HYOU,7X,3HYVU,7X,4HYVVV,6X,3HYVVMODO2076 INPT0125
   1,8X,2HYV,7X,4HYRVV,6X,4HYDVV,6X,3HYRV,7X,3HYDV,7X,4HYVRD,/,6X,    MODO2076 INPT0126
   2 12(1X,F9.2))                                                     MODO2076 INPT0127
974 FORMAT(1H0,9X,4HYRRR,7X,2HYR,7X,4HYVRR,6X,4HYDRR,6X,4HYDDD,7X,    MODO2077 INPT0128
   1 2HYD,7X,4HYVDD,6X,4HYRDD,7X,2HY0,6X,5HYVDOT,5X,5HYRDOT,/,6X,     MODO2077 INPT0129
   2 11(1X,F9.2))                                                     MODO2077 INPT0130
976 FORMAT(1H0,9X,4HNDUU,6X,3HNDU,7X,3HNOU,7X,3HNVU,7X,4HNVVV,6X,3HNVVMODO2078 INPT0131
   1,8X,2HNV,7X,4HNRVV,6X,4HNDVV,6X,3HNRV,7X,3HNDV,7X,4HNVRD,/,6X,    MODO2078 INPT0132
   2 12(1X,F9.2))                                                     MODO2078 INPT0133
977 FORMAT(1H0,9X,4HNRRR,7X,2HNR,7X,4HNVRR,6X,4HNDRR,6X,4HNDDD,7X,    MODO2079 INPT0134
   1 2HND,7X,4HNVDD,6X,4HNRDD,7X,2HN0,6X,5HNVDOT,5X,5HNRDOT,/,6X,     MODO2079 INPT0135
   2 11(1X,F9.2))                                                     MODO2079 INPT0136
980 FORMAT(1H0,6X,9HMAXRUDANG,2X,7HRUDRATE,3X,7HRUDSENT,5X,4HCK1C,6X, MODO2080 INPT0137
   1 4HCK2R,6X,4HCK3Y,6X,4HCK4V,4X,7HRUD LAG,2X,8HINIT ANG,/,6X,      MODO2080 INPT0138
   2 9(1X,F9.4))                                                      MODO2080 INPT0139
990 FORMAT(1H0,7X,8HINIT VEL,4X,4HCK5X,6X,4HCK6U,6X,4HCK7A,4X,        MODO2081 INPT0140
   1 7HACC LAG,3X,7HACCRATE,3X,7HDECRATE,3X,6HU SENT,/,6X,8(1X,F9.4)) MODO2081 INPT0141
1000 FORMAT(1H0,4X,7HXDIM(2),3X,7HYDIM(2),4X,6HPSI(2),2X,9HPASS DIST, MODO2082 INPT0142
   1 2X,8HDECLDIST,3X,5HDEPTH,5X,5HRHO W,5X,5HIPASS,5X,5HYCONT,4X,    MODO2082 INPT0143
   2 6HHEADRR,4X,6HUBREAK,/,3X,7(1X,F9.4),1X,I6,3X,3(1X,F9.4))        MODO2082 INPT0144
```

```
1010 FORMAT(1H ,5X,24HIDENTIFICATION OF SHIPS:,3X,4HSHIP,3X,6HLENGTH,6XMODO2083 INPT0145
    1,4HBEAM,2X,12HDISPLACEMENT,2X,21HPRISMATIC COEFFICIENT,/,(35X,I1, MODO2083 INPT0146
    2 2(1X,F10.3),1X,F10.1,6X,F10.3))                                 MODO2083 INPT0147
1020 FORMAT(/ 26H SHIP PASSING DISTANCE IS ,F10.2,3H FT,2X,            MODO2084 INPT0148
    1 19H DEPTH OF WATER IS ,F10.2,3H FT)                             MODO2084 INPT0149
     END                                                                       INPT0150
```

```
      SUBROUTINE HIT                                                              HIT 0001
      REAL NBAR,NINT,MT1                                                 MOD03001 HIT 0002
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DINPRN,IPRNT,ITERAT         MOD02003 HIT 0003
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),       MOD02005 HIT 0004
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)                       MOD02005 HIT 0005
      COMMON/INOLOC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS,  MOD02012 HIT 0006
     1 YCONT,HEADBR,UBREAK                                               MOD02012 HIT 0007
      COMMON/OPITIM/TIME,DELTI,SALPP(2),SBMLD(2),IST                     MOD03002 HIT 0008
      COMMON/OP3DIM/X1(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21),          MOD03004 HIT 0009
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4)          MOD03004 HIT 0010
      COMMON/OPOLOC/XREL(2),YREL(2),XCLEAR,HEAD(2),LX                    MOD03011 HIT 0011
      DIMENSION AMULT(2),CORNX(4),CORNY(4)                               MOD06001 HIT 0012
      DATA AMULT/1.0,-1.0/                                               MOD06002 HIT 0013
      XREL(1)=(XDIM(1)-XDIM(2))*COS(CI(2))+(YDIM(1)-YDIM(2))*SIN(CI(2)) MOD06003 HIT 0014
      XREL(2)=(XDIM(2)-XDIM(1))*COS(CI(1))+(YDIM(2)-YDIM(1))*SIN(CI(1)) MOD06004 HIT 0015
      YREL(1)=(YDIM(1)-YDIM(2))*COS(CI(2))-(XDIM(1)-XDIM(2))*SIN(CI(2)) MOD06005 HIT 0016
      YREL(2)=(YDIM(2)-YDIM(1))*COS(CI(1))-(XDIM(2)-XDIM(1))*SIN(CI(1)) MOD06006 HIT 0017
      IF(YREL(2) .GT. 0.0) GO TO 100                                              HIT 0018
      SIDE(1)=-1.                                                                 HIT 0019
      SIDE(2)= 1.                                                                 HIT 0020
      GO TO 105                                                                   HIT 0021
  100 CONTINUE                                                                    HIT 0022
      SIDE(1)= 1.                                                                 HIT 0023
      SIDE(2)=-1.                                                                 HIT 0024
  105 CONTINUE                                                                    HIT 0025
      IF(LX .EQ. 0) GO TO 400                                                     HIT 0026
      CIRE1=CI(1)-CI(2)                                                           HIT 0027
      CIRE2=CI(2)-CI(1)                                                           HIT 0028
      COSR1=COS(CIRE1)                                                            HIT 0029
      COSR2=COS(CIRE2)                                                            HIT 0030
      SINR1=SIN(CIRE1)                                                            HIT 0031
      SINR2=SIN(CIRE2)                                                            HIT 0032
      ALPP1=ALPP(1)*.5                                                   MOD06007 HIT 0033
      ALPP2=ALPP(2)*.5                                                   MOD06008 HIT 0034
      BMLD1=BMLD(1)*.5                                                   MOD06009 HIT 0035
      BMLD2=BMLD(2)*.5                                                   MOD06010 HIT 0036
```

```
      DO 120 I=1,2                                                     MOD06011 HIT 0037
      J=I                                                                       HIT 0038
      CORNX(I)=XREL(2)+ALPP2*COSR2*AMULT(I)+BMLD2*SINR2*SIDE(1)        MOD06012 HIT 0039
      CORNY(I)=YREL(2)+ALPP2*SINR2*AMULT(I)-BMLD2*COSR2*SIDE(1)        MOD06013 HIT 0040
      IF(ABS(CORNX(I)) .GT. ALPP1) GO TO 110                           MOD06014 HIT 0041
      IF(ABS(CORNY(I)) .GT. BMLD1) GO TO 110                           MOD06015 HIT 0042
      DIS=ALPP1-CORNX(I)                                               MOD06016 HIT 0043
      GO TO 130                                                        MOD06017 HIT 0044
  110 CONTINUE                                                         MOD06017 HIT 0045
      J=I+2                                                            MOD06018 HIT 0046
      CORNX(J)=XREL(1)+ALPP1*COSR1*AMULT(I)+BMLD1*SINR1*SIDE(2)        MOD06019 HIT 0047
      CORNY(J)=YREL(1)+ALPP1*SINR1*AMULT(I)-BMLD1*COSR1*SIDE(2)        MOD06020 HIT 0048
      IF(ABS(CORNX(J)) .GT. ALPP2) GO TO 120                           MOD06021 HIT 0049
      IF(ABS(CORNY(J)) .GT. BMLD2) GO TO 120                           MOD06022 HIT 0050
      DIS=ALPP2-CORNX(J)                                               MOD06023 HIT 0051
      GO TO 130                                                        MOD06025 HIT 0052
  120 CONTINUE                                                         MOD06026 HIT 0053
      GO TO 400                                                        MOD06027 HIT 0054
  130 CONTINUE                                                         MOD06028 HIT 0055
      I=J                                                              MOD06024 HIT 0056
      CALL OUTPUT                                                      MOD06029 HIT 0057
      IF(YREL(2) .GT. 0.0) GO TO 245                                            HIT 0058
      GO TO (210,220,230,240),I                                        MOD06031 HIT 0059
  210 WRITE(6,910) DIS                                                 MOD06032 HIT 0060
  910 FORMAT(90H0 *** THE BOW OF THE OVERTAKING SHIP (2) HAS HIT THE PORMOD06033 HIT 0061
     1T SIDE OF THE PRIVILEGED SHIP (1) ,F8.2,20H FEET AFT OF THE BOW)  MOD06033 HIT 0062
      GO TO 300                                                        MOD06034 HIT 0063
  220 WRITE(6,920) DIS                                                 MOD06035 HIT 0064
  920 FORMAT(92H0 *** THE STERN OF THE OVERTAKING SHIP (2) HAS HIT THE PMOD06036 HIT 0065
     1ORT SIDE OF THE PRIVILEGED SHIP (1) ,F8.2,20H FEET AFT OF THE BOW)MOD06036 HIT 0066
      GO TO 300                                                        MOD06037 HIT 0067
  230 WRITE(6,930) DIS                                                 MOD06038 HIT 0068
  930 FORMAT(90H0 *** THE BOW OF THE PRIVILEGED SHIP (1) HAS HIT THE STBMOD06039 HIT 0069
     1D SIDE OF THE OVERTAKING SHIP (2) ,F8.2,20H FEET AFT OF THE BOW)  MOD06039 HIT 0070
      GO TO 300                                                        MOD06040 HIT 0071
  240 WRITE(6,940) DIS                                                 MOD06041 HIT 0072
```

```
 940 FORMAT(92HO *** THE STERN OF THE PRIVILEGED SHIP (1) HAS HIT THE SMOD06042 HIT 0073
    1TBD SIDE OF THE OVERTAKING SHIP (2) ,F8.2,20H FEET AFT OF THE BOW)MOD06042 HIT 0074
     GO TO 300                                                        MOD06043 HIT 0075
 245 CONTINUE                                                         MOD06044 HIT 0076
     GO TO (250,260,270,280),I                                        MOD06044 HIT 0077
 250 WRITE(6,950) DIS                                                 MOD06045 HIT 0078
 950 FORMAT(90HO *** THE BOW OF THE OVERTAKING SHIP (2) HAS HIT THE STBMOD06046 HIT 0079
    1D SIDE OF THE PRIVILEGED SHIP (1) ,F8.2,20H FEET AFT OF THE BOW)  MOD06046 HIT 0080
     GO TO 300                                                        MOD06047 HIT 0081
 260 WRITE(6,960) DIS                                                 MOD06048 HIT 0082
 960 FORMAT(92HO *** THE STERN OF THE OVERTAKING SHIP (2) HAS HIT THE SMOD06049 HIT 0083
    1TBD SIDE OF THE PRIVILEGED SHIP (1) ,F8.2,20H FEET AFT OF THE BOW)MOD06049 HIT 0084
     GO TO 300                                                        MOD06050 HIT 0085
 270 WRITE(6,970) DIS                                                 MOD06051 HIT 0086
 970 FORMAT(90HO *** THE BOW OF THE PRIVILEGED SHIP (1) HAS HIT THE PORMOD06052 HIT 0087
    1T SIDE OF THE OVERTAKING SHIP (2) ,F8.2,20H FEET AFT OF THE BOW)  MOD06052 HIT 0088
     GO TO 300                                                        MOD06053 HIT 0089
 280 WRITE(6,980) DIS                                                 MOD06054 HIT 0090
 980 FORMAT(92HO *** THE STERN OF THE PRIVILEGED SHIP (1) HAS HIT THE PMOD06055 HIT 0091
    1ORT SIDE OF THE OVERTAKING SHIP (2) ,F8.2,20H FEET AFT OF THE BOW)MOD06055 HIT 0092
 300 CONTINUE                                                         MOD06056 HIT 0093
C    END RUN WHEN COLLISION OCCURS                                             HIT 0094
     ENDTIM=TIME                                                      MOD06057 HIT 0095
 400 RETURN                                                           MOD06058 HIT 0096
     END                                                                       HIT 0097
```

```
      SUBROUTINE DATAPL                                                 MOD01000 PLOT0001
C                                                                                PLOT0002
C     THIS SUBROUTINE PLOTS THE LOCATION OF SHIPS IN TIME POSITION               PLOT0003
C     DATA ON TIME PERCID, SHIP VELOCITY, AND ANGULAR VELOCITY                   PLOT0004
C                                                                                PLOT0005
      REAL NBAR,NINI,MTI                                                MOD03001 PLOT0006
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DINPRN,IPRNT,ITERAT        MOD02003 PLOT0007
      COMMON/IN2PLT/SCALDG,SRUDL,SIZLTR,TIMPLT,DINPLT,SPCPLT            MOD02004 PLOT0008
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),      MOD02005 PLOT0009
     2 A22(2),A33(2),TPI(2),MTI(2),XLCG(2),NSTA(4)                      MOD02005 PLOT0010
      COMMON/INOLCC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MOD02012 PLOT0011
     1 YCONT,HEADBR,UBREAK                                              MOD02012 PLOT0012
      COMMON/OPITIM/TIME,DELTI,SALPP(2),SBMLD(2),IST                    MOD03002 PLOT0013
      COMMON/OP2CON/PI,PIRO4,DEGRAD,RADDEG,FND(2),FPSKTS                MOD03003 PLOT0014
      COMMON/OP8RUD/DR(2),DRCAPT(2)                                     MOD03009 PLOT0015
      COMMON/OP9SPD/UDIM(2),DELU(2),UCDIM(2),V(2),VDIM(2),VODIM(2),R(2),MOD03010 PLOT0016
     1 RDIM(2),UCAPT(2)                                                 MOD03010 PLOT0017
C     THESE DIMENSIONS ARE THE OPERATING VARIABLES IN SUBROUTINE                 PLOT0018
      DIMENSION ANG(2),ANGR(2),UKTS(2),XPAGE(2),YPAGE(2),                        PLOT0019
     1 XMI1(2),YMI1(2),XMI2(2),YMI2(2),XPT1(2),YPT1(2),XPT2(2),YPT2(2),          PLOT0020
     2 XPT3(2),YPT3(2),XPT4(2),YPT4(2),XPT5(2),YPT5(2),XPT6(2),YPT6(2)           PLOT0021
C                                                                                PLOT0022
C     CONVERT SPEED, YAW ANGLE, AND RUDDER ANGLE INTO RIGHT UNITS                PLOT0023
      DO 100 I=1,2                                                               PLOT0024
      UKTS(I)=UDIM(I)*FPSKTS                                                     PLOT0025
      ANG(I)=-CI(I)*RADDEG                                                       PLOT0026
      ANGR(I)=DR(I)*RADDEG                                                       PLOT0027
C     DEFINE PLOT LOCATION OF SHIP CENTER POINTS                                 PLOT0028
      XPAGE(I)=XDIM(I)/SCALDG                                                    PLOT0029
      YPAGE(I)=-YDIM(I)/SCALDG                                                   PLOT0030
      XMI1(I)=(SBMLD(I)/2.)*SIN(CI(I))                                           PLOT0031
      YMI1(I)=(SBMLD(I)/2.)*COS(CI(I))                                           PLOT0032
      XMI2(I)=(SALPP(I)/2.)*COS(CI(I))                                           PLOT0033
      YMI2(I)=(SALPP(I)/2.)*SIN(CI(I))                                           PLOT0034
C     PLOTTED POINTS LOCATION PORT=1,BOW=2,STBD=3,S STERN=4,STERN=5,P STERN=6    PLOT0035
C     AXES SYSTEM TRANSFER Y POSITIVE DOWN TO Y POSITIVE UP                      PLOT0036
```

```
      XPT1(I)=XPAGE(I)+XMI1(I)                                                PLOT0037
      YPT1(I)=YPAGE(I)+YMI1(I)                                                PLOT0038
      XPT2(I)=XPAGE(I)+XMI2(I)                                                PLOT0039
      YPT2(I)=YPAGE(I)-YMI2(I)                                                PLOT0040
      XPT3(I)=XPAGE(I)-XMI1(I)                                                PLOT0041
      YPT3(I)=YPAGE(I)-YMI1(I)                                                PLOT0042
      XPT4(I)=XPAGE(I)-XMI2(I)-XMI1(I)                                        PLOT0043
      YPT4(I)=YPAGE(I)+YMI2(I)-YMI1(I)                                        PLOT0044
      XPT5(I)=XPAGE(I)-XMI2(I)                                                PLOT0045
      YPT5(I)=YPAGE(I)+YMI2(I)                                                PLOT0046
      XPT6(I)=XPAGE(I)-XMI2(I)+XMI1(I)                                        PLOT0047
      YPT6(I)=YPAGE(I)+YMI2(I)+YMI1(I)                                        PLOT0048
C     DEFINE ABSOLUTE RUDDER ANGLE                                            PLOT0049
      ANGR(I)=(ANG(I)+180.)-ANGR(I)                                           PLOT0050
  100 CONTINUE                                                                PLOT0051
C     START PLOTTING                                                          PLOT0052
      IF (IST .NE.  0) GO TO 110   IST = 1                                    PLOT0053
      CALL PLOTS(IDUM,IDUM,9)                                                 PLOT0054
      CALL PLOT(0.0,6.4,-3)                                                   PLOT0055
C     DEFINE FIXED TIME INITIAL ORIGIN                                        PLOT0056
      CALL SYMBOL(0.0,0.0,0.32,3,0.0,-1)                                      PLOT0057
C     CONDITIONAL CONTINUATION OF PLOTTING                                    PLOT0058
  110 CONTINUE                                                        MOD03037 PLOT0059
C     SPACE PLOT ON PAGE                                                      PLOT0060
      CALL PLOT (SPCPLT,0.0,-3)                                               PLOT0061
C     SHIP 1 PLOT                                                             PLOT0062
      CALL SYMBOL(XPAGE(1),YPAGE(1),0.08,113,ANG(1),-1)                       PLOT0063
      CALL PLOT(XPT1(1),YPT1(1),3)                                            PLOT0064
      CALL PLOT(XPT2(1),YPT2(1),2)                                            PLOT0065
      CALL PLOT(XPT3(1),YPT3(1),2)                                            PLOT0066
      CALL PLOT(XPT4(1),YPT4(1),2)                                            PLOT0067
      CALL SYMBOL(XPT5(1),YPT5(1),SRUDL,15,ANGR(1),-2)                        PLOT0068
      CALL PLOT(XPT5(1),YPT5(1),3)                                            PLOT0069
      CALL PLOT(XPT6(1),YPT6(1),2)                                            PLOT0070
      CALL PLOT(XPT1(1),YPT1(1),2)                                            PLOT0071
C     SHIP 2 PLOT                                                             PLOT0072
                                                                           PAGE  16
```

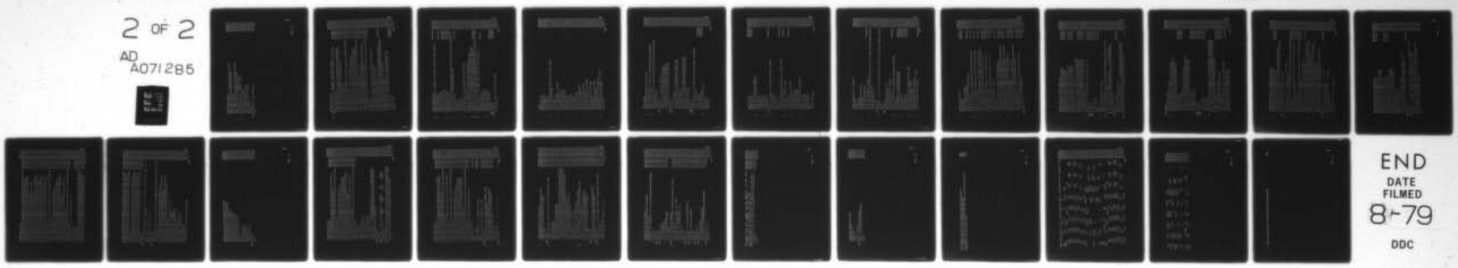
```
      CALL SYMBOL(XPAGE(2),YPAGE(2),0.08,114,ANG(2),-1)                 PLOT0073
      CALL PLOT(XPT1(2),YPT1(2),3)                                      PLOT0074
      CALL PLOT(XPT2(2),YPT2(2),2)                                      PLOT0075
      CALL PLOT(XPT3(2),YPT3(2),2)                                      PLOT0076
      CALL PLOT(XPT4(2),YPT4(2),2)                                      PLOT0077
      CALL SYMBOL(XPT5(2),YPT5(2),SRUDL,15,ANCR(2),-2)                  PLOT0078
      CALL PLOT(XPT5(2),YPT5(2),3)                                      PLOT0079
      CALL PLOT(XPT6(2),YPT6(2),2)                                      PLOT0080
      CALL PLOT(XPT1(2),YPT1(2),2)                                      PLOT0081
C     PLOT OUTPUT SHIPS DATA, VELOCITIES, AND ANGLES                    PLOT0082
      CALL SYMBOL(XPT1(1),-3.0,SIZLTR,'TIME=',0.0,5)                    PLOT0083
      CALL NUMBER(999.,999.,SIZLTR,TIME,0.0,0)                          PLOT0084
      CALL SYMBOL(XPT1(1),-3.2,SIZLTR,'U(1)=',0.0,5)                    PLOT0085
      CALL NUMBER(999.,999.,SIZLTR,UKTS(1),0.0,2)                       PLOT0086
      ANG(1)=-ANG(1)                                                    PLOT0087
      CALL SYMBOL(XPT1(1),-3.4,SIZLTR,'PSI(1)=',0.0,7)                  PLOT0088
      CALL NUMBER(999.,999.,SIZLTR,ANC(1),0.0,2)                        PLOT0089
      CALL SYMBOL(XPT1(1),-3.6,SIZLTR,'V(1)=',0.0,5)                    PLOT0090
      CALL NUMBER(999.,999.,SIZLTR,VDIM(1),0.0,3)                       PLOT0091
      CALL SYMBOL(XPT1(1),-3.8,SIZLTR,'R(1)=',0.0,5)                    PLOT0092
      CALL NUMBER(999.,999.,SIZLTR,RDIM(1),0.0,4)                       PLOT0093
      DRA=DR(1)*RADDEG                                                  PLOT0094
      CALL SYMBOL(XPT1(1),-4.0,SIZLTR,'DR(1)=',0.0,6)                   PLOT0095
      CALL NUMBER(999.,999.,SIZLTR,DRA,0.0,2)                           PLOT0096
      CALL SYMBOL(XPT1(1),-4.2,SIZLTR,'U(2)=',0.0,5)                    PLOT0097
      CALL NUMBER(999.,999.,SIZLTR,UKTS(2),0.0,2)                       PLOT0098
      ANG(2)=-ANG(2)                                                    PLOT0099
      CALL SYMBOL(XPT1(1),-4.4,SIZLTR,'PSI(2)=',0.0,7)                  PLOT0100
      CALL NUMBER(999.,999.,SIZLTR,ANG(2),0.0,2)                        PLOT0101
      CALL SYMBOL(XPT1(1),-4.6,SIZLTR,'V(2)=',0.0,5)                    PLOT0102
      CALL NUMBER(999.,999.,SIZLTR,VDIM(2),0.0,3)                       PLOT0103
      CALL SYMBOL(XPT1(1),-4.8,SIZLTR,'R(2)=',0.0,5)                    PLOT0104
      CALL NUMBER(999.,999.,SIZLTR,RDIM(2),0.0,4)                       PLOT0105
      DRA=DR(2)*RADDEG                                                  PLOT0106
      CALL SYMBOL(XPT1(1),-5.0,SIZLTR,'DR(2)=',0.0,6)                   PLOT0107
      CALL NUMBER(999.,999.,SIZLTR,DRA,0.0,2)                           PLOT0108
```

AD-A071 285 MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN E--ETC F/G 13/10
THE EFFECTS OF INTERACTION FORCES BETWEEN SHIPS IN PROXIMITY ON--ETC(U)
JUN 78 R E CONRAD N00014-75-C-1006

UNCLASSIFIED NL

2 OF 2

AD A071285



END
DATE
FILMED
8-79
DDC

```
      DX=XDIM(2)-XDIM(1)                                               PLOT0109
      CALL SYMBOL(XPT1(1),-5.2,SIZLTR,'X2-X1=',0.0,6)                  PLOT0110
      CALL NUMBER(999.,999.,SIZLTR,DX,0.0,2)                           PLOT0111
      DY=YDIM(2)-YDIM(1)                                               PLOT0112
      CALL SYMBOL(XPT1(1),-5.4,SIZLTR,'Y2-Y1=',0.0,6)                  PLOT0113
      CALL NUMBER(999.,999.,SIZLTR,DY,0.0,2)                           PLOT0114
C     CONDITIONAL RETURN TO MAIN PROGRAM                               PLOT0115
      IF((TIME+DELT) .LE. ENDTIM) RETURN                               PLOT0116
C     END OF PLOT SUBROUTINE                                           PLOT0117
      SPCPLT=SPCPLT+XPAGE(1)                                           PLOT0118
      CALL PLOT (SPCPLT,0.0,-3)                                        PLOT0119
      CALL ENDPLT (10.0,0.0,999)                                       PLOT0120
      WRITE(6,900)                                                     PLOT0121
      RETURN                                                           PLOT0122
  900 FORMAT(15H1 PLOT COMPLETE)                                       PLOT0123
      END                                                              PLOT0124
```

```
      SUBROUTINE INTER                                                   INTR0001
C     THIS IS A PROGRAM TO CALCULATE INTERACTION FORCES                  INTR0002
C     USING A SLENDER BODY APPROXIAMATION AND INCLUDING END EFFECTS  00000010 INTR0003
      REAL NBAR,NINT,MT1                                           MOD03001 INTR0004
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT     MOD02003 INTR0005
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),   MOD02005 INTR0006
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)                  MOD02005 INTR0007
      COMMON/IN5BEM/BEAM(2,21)                                      MOD02007 INTR0008
      COMMON/IN6DRF/RDRAFT(2,21)                                    MOD02008 INTR0009
      COMMON/INOLCC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MOD02012 INTR0010
     1 YCONT,HEADOR,UBREAK                                          MOD02012 INTR0011
      COMMON/OP1TIM/TIME,DELTI,SALPP(2),SBMLD(2),IST                MOD03002 INTR0012
      COMMON/OP2CON/PI,PIR04,DEGRAD,RADDEG,FND(2),FPSKTS            MOD03003 INTR0013
      COMMON/OP3DIM/X1(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21),     MOD03004 INTR0014
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4)     MOD03004 INTR0015
      COMMON/OP4SMD/SM(4,21),SUM(4,21),SDY(4,21),SUDY(4,21),SDYV(4,21), MOD03005 INTR0016
     1 SDYR(4,21),SDZ(4,21),SUDZ(4,21)                              MOD03005 INTR0017
      COMMON/OP5VEL/UQA(2,21),UQY(2,21),UQZ(2,21)                   MOD03006 INTR0018
      COMMON/OP6FCR/XBAR(2),YBAR(2),NBAR(2),XINT(2),YINT(2),NINT(2), MOD03007 INTR0019
     1 FXT(2),FYT(2),FZT(2),RXT(2),RYT(2),RZT(2)                    MOD03007 INTR0020
      COMMON/OP9SPD/UDIM(2),DELU(2),UODIM(2),V(2),VDIM(2),VODIM(2),R(2),MOD03010 INTR0021
     1 RDIM(2),UCAPT(2)                                             MOD03010 INTR0022
      DIMENSION                                                          INTR0023
     1 OSM(2,21),OSDY(2,21),OSDZ(2,21),OSDYR(2,21),OUQY(2,21),           INTR0024
     2 QA2(21),DQA2DY(21),DQA2DZ(21),CAP(2,21),                          INTR0025
     3 QY2(21),DQY2DY(21),DQY2DZ(21),QY(2,21),                           INTR0026
     4 QZ2(21),DQZ2DZ(21),QZ(2,21),                                      INTR0027
     5 DQADY(2,21),DQADZ(2,21),DQYDY(2,21),DQYDZ(2,21),DQZDZ(2,21), MOD04031 INTR0028
     6 DSMDT(2,21),DSDYDT(2,21),DSDZDT(2,21),DSYRDT(2,21),DUQYDT(2,21),  INTR0029
     7 FX(21),FY(21),FZ(21),RX(21),RY(21),RZ(21)                         INTR0030
     8 ,UQA2(21),UQY2(21),UQZ2(21)                                       INTR0031
     9 ,FXSMDT(21),FYDYDT(21),RZQADY(21),RZQAVR(21),RZDT(21)             INTR0032
C     CALCULATE INTERACTION FORCES AND MOMENTS FOR SHIP  I               INTR0033
      DO 110 I=1,2                                                 MOD04035 INTR0034
      NSTAI=NSTA(I)                                                MOD04036 INTR0035
      J=I+2                                                              INTR0036
```

```
      DO 100 L=1,NSTAI                                                  MOD04038 INTR0037
C     CREAT ORIGINAL SET OF SOURCE AND DIPOLE STRENGTHS FOR UNSTEADY             INTR0038
C     FLOW CALCULATIONS.                                                         INTR0039
      OSM(I,L)=SM(I,L)                                                  MOD04039 INTR0040
      OSDY(I,L)=SDY(I,L)                                                         INTR0041
      OSDZ(I,L)=SDZ(I,L)                                                MOD04041 INTR0042
      OSDYR(I,L)=SDYR(I,L)                                              MOD04043 INTR0043
C     OSDZQ(I,L)=SDZQ(I,L)                                              MOD04044 INTR0044
      OUQY(I,L)=UQY(I,L)                                                MOD04046 INTR0045
C     OUQZ(I,L)=UQZ(I,L)                                                MOD04047 INTR0046
C     CALCULATE INITIAL SOURCE AND DIPOLE STRENGTHS BASED ON CURRENT CONDITIONS  INTR0047
      SM(I,L)=.5*UDIM(I)*RYZ(I,L)*DRYZDX(I,L)                                    INTR0048
      SUM(I,L)=SM(I,L)                                                  MOD04011 INTR0049
      QY(I,L)=0.                                                                 INTR0050
      QZ(I,L)=0.                                                                 INTR0051
      UQY(I,L)=0.0                                                               INTR0052
      UQZ(I,L)=0.0                                                               INTR0053
C     CONTRIBUTION OF LATERAL AND VERTICAL MOTIONS                               INTR0054
C     FOR SHIP 1 AND SHIP 2                                                      INTR0055
      SDYV(I,L)=VDIM(I)*.25*(1.+A22(I))*RY2(I,L)**2                              INTR0056
      SDYR(I,L)=RDIM(I)*X1(I,L)*.25*(1.+A22(I))*RY2(I,L)**2                      INTR0057
C     VERTICAL MOTION IS NOT CALCULATED ( WDIM AND QDIM ARE ZERO )               INTR0058
C     SDZW(I,L)=WDIM(I)*.25*RDRAFT(I,L)*RDRAFT(I,L)*(1.+A33(I))         MOD04054 INTR0059
C     SDZQ(I,L)=-QDIM(I)*X1(I,L)*.25*RDRAFT(I,L)*RDRAFT(I,L)*(1.+A33(I))MOD04055 INTR0060
C     CREATE IMAGE OF SHIP 1 AND SHIP 2 AS SHIP 3 AND SHIP 4                     INTR0061
C     DUPLICATE SOURCE AND DIPOLE STRENGTH FOR SHIP 3 AND SHIP 4                 INTR0062
      SM(J,L)=SM(I,L)                                                   MOD04    INTR0063
      SDYV(J,L)=SDYV(I,L)                                                        INTR0064
      SDYR(J,L)=SDYR(I,L)                                                        INTR0065
C     SDZW(J,L)=SDZW(I,L)                                                        INTR0066
C     SDZQ(J,L)=SDZQ(I,L)                                                        INTR0067
      SUM(J,L)=SUM(I,L)                                                 MOD04019 INTR0068
  100 CONTINUE                                                          MOD04059 INTR0069
  110 CONTINUE                                                          MOD04060 INTR0070
C     CALCULATE INITIAL DIPOLE STRENGTHS                                         INTR0071
      DO 160 I=1,2                                                               INTR0072
                                                                         PAGE  20
```

```
      J=I+2                                                             INTR0073
      NSTAI=NSTA(I)                                                     INTR0074
      CYI=COS(CI(I))                                                    INTR0075
      SYI=SIN(CI(I))                                                    INTR0076
      STI=TRIM(I)                                                       INTR0077
      DO 140 K=1,4                                                      INTR0078
C     ITERATION CANCELLING EFFECT DUE TO BODY ITSELF                    INTR0079
      IF(I.EQ.K) GO TO 140                                              INTR0080
      DXK=DX(K)                                                         INTR0081
      NSTAK=NSTA(K)                                                     INTR0082
C     DEFINE RELATIVE POSITIONS                                         INTR0083
      PSI=CI(I)-CI(K)                                                   INTR0084
      XX=XDIM(I)-XDIM(K)                                                INTR0085
      YK=YDIM(I)-YDIM(K)                                                INTR0086
      ZK=ZDIM(I)-ZDIM(K)                                                INTR0087
      CPSI=COS(PSI)                                                     INTR0088
      SPSI=SIN(PSI)                                                     INTR0089
      CYK=COS(CI(K))                                                    INTR0090
      SYK=SIN(CI(K))                                                    INTR0091
      STK=TRIM(K)                                                       INTR0092
      XDK=CPSI+STK*STI                                                  INTR0093
      DO 130 L=1,NSTAI                                                  INTR0094
      YY=YK+BEAM(I,L)*SIDE(I)                                           INTR0095
      ZZ=ZK-RDRAFT(I,L)                                                 INTR0096
      XDI=XX*CYI+YY*SYI-ZZ*STI                                          INTR0097
      YDI=-XX*SYI+YY*CYI                                                INTR0098
      ZDI=XX*CYI*STI+YY*STI*SYI+ZZ                                      INTR0099
      DO 120 M=1,NSTAK                                                  INTR0100
      SDYTOT=SDYV(K,M)+SDYR(K,M)                                        INTR0101
      WSM=SUM(K,M)                                                      INTR0102
      XD=XDI+X1(I,L)-X1(K,M)*XDK                                        INTR0103
      YD=YDI+X1(K,M)*SPSI                                               INTR0104
      ZD=ZDI-X1(K,M)*(STI*CPSI-STK)                                     INTR0105
C     RADIAL DISTANCE FROM SHIP I TO SHIP K                             INTR0106
      RD=SQRT(XD*XD+YD*YD+ZD*ZD)                                        INTR0107
      R3=1./RD**3                                                       INTR0108
```

```
      R5=1./RD**5                                                       INTRO109
      CONST1=SPSI*XD+CPSI*YD+STI*SPSI*ZD                                INTRO110
C     FLOW IN Y DIRECTION                                               INTRO111
      QY2(M)=SM(K,M)*YD*R3+3.*YD*SDYTOT*CONST1*R5-SDYTOT*CPSI*R3        INTRO112
C     FLOW IN Z DIRECTION                                               INTRO113
      QZ2(M)=SM(K,M)*ZD*R3+3.*ZD*SDYTOT*CONST1*R5-SDYTOT*SPSI*STI*R3    INTRO114
      UQY2(M)=WSM*YD*R3                                                 INTRO115
      UQZ2(M)=WSM*ZD*R3                                                 INTRO116
  120 CONTINUE                                                          INTRO117
C     SUMMED FLOW AT STATIONS OF SHIP                                   INTRO118
      QY(I,L)=QY(I,L)+SIMPSN(DXK,QY2,NSTAK,M)                           INTRO119
      QZ(I,L)=QZ(I,L)+SIMPSN(DXK,QZ2,NSTAK,M)                           INTRO120
      UQY(I,L)=UQY(I,L)+SIMPSN(DXK,UQY2,NSTAK,M)                        INTRO121
      UQZ(I,L)=UQZ(I,L)+SIMPSN(DXK,UQZ2,NSTAK,M)                        INTRO122
  130 CONTINUE                                                          INTRO123
  140 CONTINUE                                                          INTRO124
      DO 150 L=1,NSTAI                                                  INTRO125
      SDY(I,L)=-QY(I,L)*.25*(1.+A22(I))*RY2(I,L)**2                     INTRO126
      SDZ(I,L)=-QZ(I,L)*.25*(1.+A33(I))*RZ3(I,L)**2                     INTRO127
      SDY(J,L)=SDY(I,L)                                                 INTRO128
      SDZ(J,L)=-SDZ(I,L)                                                INTRO129
      SUDY(I,L)=-UQY(I,L)*.25*(1.+A22(I))*RY2(I,L)**2                   INTRO130
      SUDZ(I,L)=-UQZ(I,L)*.25*(1.+A33(I))*RZ3(I,L)**2                   INTRO131
      SUDY(J,L)=SUDY(I,L)                                               INTRO132
      SUDZ(J,L)=-SUDZ(I,L)                                              INTRO133
  150 CONTINUE                                                          INTRO134
  160 CONTINUE                                                          INTRO135
C     START ITERATION OF SOURCE STRENGTH AND DIPOLE STRENGTHS           INTRO136
      DO 250 II=1,ITERAT                                                INTRO137
      DO 220 I=1,2                                             MOD04065 INTRO138
      NSTAI=NSTA(I)                                            MOD04065 INTRO139
      DO 170 L=1,NSTAI                                         MOD04065 INTRO140
C     ZEROING FLOW VELOCITIES                                           INTRO141
      QAP(I,L)=0.                                                       INTRO142
      QY(I,L)=0.                                                        INTRO143
      QZ(I,L)=0.                                                        INTRO144
```

```
      UQA(I,L)=0.0                                                      MOD04066 INTR0145
      UQY(I,L)=0.0                                                      MOD04067 INTR0146
      UQZ(I,L)=0.0                                                      MOD04068 INTR0147
      IF(II .NE. ITERAT) GO TO 170                                               INTR0148
C     ZEROING FLOW VELOCITY GRADIENTS                                            INTR0149
      DQADY(I,L)=0.                                                              INTR0150
      DQADZ(I,L)=0.                                                              INTR0151
      DQYDY(I,L)=0.                                                              INTR0152
      DQYDZ(I,L)=0.                                                              INTR0153
C     DQZDY(I,L)=0.                                                              INTR0154
      DQZDZ(I,L)=0.                                                              INTR0155
  170 CONTINUE                                                          MOD04070 INTR0156
C     DEFINE FUNCTIONS OF SINE AND COSINE OF ANGLES                              INTR0157
      CYI=COS(CI(I))                                                             INTR0158
      SYI=SIN(CI(I))                                                             INTR0159
      STI=TRIM(I)                                                                INTR0160
      CTI=1.                                                                     INTR0161
      DO 210 K=1,4                                                      MOD04071 INTR0162
C     ITERATION CANCELLING EFFECT DUE TO BODY ITSELF                             INTR0163
      IF(I.EQ.K) GO TO 210                                              MOD04072 INTR0164
C     INCREMENTAL STATION LENGTH                                                 INTR0165
      DXK=DX(K)                                                                  INTR0166
      NSTAK=NSTA(K)                                                     MOD04073 INTR0167
C     DEFINE RELATIVE POSITIONS                                                  INTR0168
      PSI=CI(I)-CI(K)                                                            INTR0169
      XX=XDIM(I)-XDIM(K)                                                         INTR0170
      YK=YDIM(I)-YDIM(K)                                                         INTR0171
      ZK=ZDIM(I)-ZDIM(K)                                                         INTR0172
C     DEFINE ORIENTATION FUNCTIONS                                               INTR0173
      CPSI=COS(PSI)                                                              INTR0174
      SPSI=SIN(PSI)                                                              INTR0175
      CYK=COS(CI(K))                                                             INTR0176
      SYK=SIN(CI(K))                                                             INTR0177
      STK=TRIM(K)                                                                INTR0178
      CTK=1.                                                                     INTR0179
      XDK=CPSI+STK*STI                                                           INTR0180
```

```
C       DEFINE CINSTANTS OF OPERATICN                                           INTRO181
        A=CTI*SPSI                                                              INTRO182
        B=CPSI                                                                  INTRO183
        C=STI*SPSI                                                              INTRO184
        D=CPSI*STK*CTI-STI*CTK                                                  INTRO185
        E=-STK*SPSI                                                             INTRO186
        F=CPSI*STK*STI+CTK*CTI                                                  INTRO187
        DO 200 L=1,NSTAI                                               MOD04074 INTRO188
        IF(II .EQ. ITERAT) GO TO 180                                            INTRO189
C       CALCULATE INDUCED FLOW AT BOUNDARY OF SHIP I TO RESIZE SOURCES AND DIPOLES INTRO190
        YY=YK+BEAM(I,L)*SIDE(I)                                                 INTRO191
        ZZ=ZK-RDRAFT(I,L)                                                       INTRO192
        GO TO 185                                                               INTRO193
  180   CONTINUE                                                                INTRO194
C       CALCULATE INDUCED FLOW AT CENTERLINE OF SHIP I FOR LAGALLY FORCES (II=NKK) INTRO195
        YY=YK                                                                   INTRO196
        ZZ=ZK                                                                   INTRO197
  185   CONTINUE                                                                INTRO198
        XDI=XX*CYI+YY*SYI-ZZ*STI                                                INTRO199
        YDI=-XX*SYI+YY*CYI                                                      INTRO200
        ZDI=XX*CYI*STI+YY*STI*SYI+ZZ                                            INTRO201
        DO 190 M=1,NSTAK                                               MOD04075 INTRO202
C       WORKING PARAMETERS OF SOURCE AND DIPOLE STRENGTHS                       INTRO203
        FSM=SM(K,M)                                                             INTRO204
        SDYTOT=SDY(K,M)+SDYV(K,M)+SDYR(K,M)                            MOD04154 INTRO205
C       SDZTOT=SDZ(K,M)+SDZQ(K,M)+SDZW(K,M)                            MOD04155 INTRO206
        SDZTOT=SDZ(K,M)                                                MOD04155 INTRO207
        WSM=SUM(K,M)                                                   MOD04076 INTRO208
        WSDY=SUDY(K,M)                                                 MOD04077 INTRO209
        WSDZ=SUDZ(K,M)                                                 MOD04078 INTRO210
C       DEFINE REFERENCE TO SHIP 1 REFENCE AXIS                                 INTRO211
        XD=XDI+X1(I,L)-X1(K,M)*XDK                                              INTRO212
        YD=YDI+X1(K,M)*SPSI                                                     INTRO213
        ZD=ZDI-X1(K,M)*(STI*CPSI-STK)                                           INTRO214
C       RADIAL DISTANCE FROM SHIP I TO SHIP K                                   INTRO215
        RD=SQRT(XD*XD+YD*YD+ZD*ZD)                                     MOD04078 INTRO216
```

```
C       OPERATING CONSTANTS                                                      INTRO217
        R3=1./RD**3                                                     MOD04156 INTRO218
        R5=1./RD**5                                                     MOD04157 INTRO219
        CONST1=(A*XD+B*YD+C*ZD)                                                  INTRO220
        CONST2=(D*XD+E*YD+F*ZD)                                                  INTRO221
        SYZC12=SDYTOT*CONST1+SDZTOT*CONST2                              MOD04158 INTRO222
C       FLOW ALONG AXIS                                                          INTRO223
        OA2(M)=FSM*XD*R3+3.*XD*SYZC12*R5-(SDYTOT*A+SDZTOT*D)*R3         MOD04159 INTRO224
C       FLOW IN Y DIRECTION                                                      INTRO225
        OY2(M)=FSM*YD*R3+3.*YD*SYZC12*R5-(SDYTOT*B+SDZTOT*E)*R3         MOD04160 INTRO226
C       FLOW IN Z DIRECTION                                                      INTRO227
        OZ2(M)=FSM*ZD*R3+3.*ZD*SYZC12*R5-(SDYTOT*C+SDZTOT*F)*R3         MOD04161 INTRO228
C       THE UNCORRECTED STATE OF FLOW IN AXIAL, Y AND Z DIRECTION                INTRO229
        UOA2(M)=WSM*XD*R3+3.*XD*(WSDY*CONST1+WSDZ*CONST2)*R5            MOD04162 INTRO230
      1 -(WSDY*A+WSDZ*D)*R3                                             MOD04162 INTRO231
        UOY2(M)=WSM*YD*R3+3.*YD*(WSDY*CONST1+WSDZ*CONST2)*R5            MOD04163 INTRO232
      1 -(WSDY*B+WSDZ*E)*R3                                             MOD04163 INTRO233
        UOZ2(M)=WSM*ZD*R3+3.*ZD*(WSDY*CONST1+WSDZ*CONST2)*R5            MOD04164 INTRO234
      1 -(WSDY*C+WSDZ*F)*R3                                             MOD04164 INTRO235
        IF (II .NE. ITERAT) GO TO 190                                            INTRO236
        R7=1./RD**7                                                     MOD04158 INTRO237
C       VELOCITY GRADIENT ALONG AXIS DOA2DY, DOA2DZ                              INTRO238
        DOA2DY(M)=-3.*FSM*XD*YD*R5-15.*XD*YD*SYZC12*R7                  MOD04165 INTRO239
      1 +3.*XD*(SDYTOT*B+SDZTOT*E)*R5+3.*YD*(SDYTOT*A+SDZTOT*D)*R5      MOD04165 INTRO240
        DOA2DZ(M)=-3.*FSM*XD*ZD*R5-15.*XD*ZD*SYZC12*R7                  MOD04166 INTRO241
      1 +3.*XD*(SDYTOT*C+SDZTOT*F)*R5+3.*ZD*(SDYTOT*A+SDZTOT*D)*R5      MOD04166 INTRO242
C       VELOCITY GRADIENT IN Y DIRECTION DOY2DY, DOY2DZ                          INTRO243
        DOY2DY(M)=FSM*R3-3.*YD*YD*FSM*R5-15.*YD*YD*SYZC12*R7            MOD04167 INTRO244
      1 +9.*YD*(SDYTOT*B+SDZTOT*E)*R5                                   MOD04167 INTRO245
        DOY2DZ(M)=-3.*FSM*YD*ZD*R5-15.*YD*ZD*SYZC12*R7                  MOD04168 INTRO246
      1 +3.*YD*(SDYTOT*C+SDZTOT*F)*R5+3.*ZD*(SDYTOT*B+SDZTOT*E)*R5      MOD04168 INTRO247
C       VELOCITY GRADIENT IN Z DIRECTION DOZ2DY, DOZ2DZ                          INTRO248
C       DOZ2DY(M)=DOY2DZ(M)                                             MOD04169 INTRO249
        DOZ2DZ(M)=FSM*R3-3.*ZD*ZD*FSM*R5-15.*ZD*ZD*SYZC12*R7            MOD04170 INTRO250
      1 +9.*ZD*(SDYTOT*C+SDZTOT*F)*R5                                   MOD04170 INTRO251
  190 CONTINUE                                                          MOD04088 INTRO252
```

```
C     SUMMED FLOW AT STATIONS OF SHIP                                              INTRO253
      QAP(I,L)=QAP(I,L)+SIMPSN(DXK,QA2,NSTAK,M)                           MOD04089 INTRO254
      QY(I,L)=QY(I,L)+SIMPSN(DXK,QY2,NSTAK,M)                             MOD04090 INTRO255
      QZ(I,L)=QZ(I,L)+SIMPSN(DXK,QZ2,NSTAK,M)                             MOD04091 INTRO256
C     SUMMATION OF UNCORRECTED STATE FLOWS                                         INTRO257
      UQA(I,L)=UQA(I,L)+SIMPSN(DXK,UQA2,NSTAK,M)                          MOD04092 INTRO258
      UQY(I,L)=UQY(I,L)+SIMPSN(DXK,UQY2,NSTAK,M)                          MOD04093 INTRO259
      UQZ(I,L)=UQZ(I,L)+SIMPSN(DXK,UQZ2,NSTAK,M)                          MOD04094 INTRO260
      IF (II .NE. ITERAT) GO TO 200                                                INTRO261
C     LAST ITERATION SUMMED VEL GRAD ALONG SHIP'S LENGTH                           INTRO262
      DQADY(I,L)=DQADY(I,L)+SIMPSN(DXK,DQA2DY,NSTAK,M)                    MOD04096 INTRO263
      DQADZ(I,L)=DQADZ(I,L)+SIMPSN(DXK,DQA2DZ,NSTAK,M)                    MOD04097 INTRO264
      DQYDY(I,L)=DQYDY(I,L)+SIMPSN(DXK,DQY2DY,NSTAK,M)                    MOD04098 INTRO265
      DQYDZ(I,L)=DQYDZ(I,L)+SIMPSN(DXK,DQY2DZ,NSTAK,M)                    MOD04099 INTRO266
C     DQZDY(I,L)=DQYDZ(I,L)                                                        INTRO267
      DQZDZ(I,L)=DQZDZ(I,L)+SIMPSN(DXK,DQZ2DZ,NSTAK,M)                    MOD04101 INTRO268
  200 CONTINUE                                                            MOD04102 INTRO269
  210 CONTINUE                                                            MOD04103 INTRO270
  220 CONTINUE                                                            MOD04104 INTRO271
      DO 240 I=1,2                                                        MOD04105 INTRO272
      NSTAI=NSTA(I)                                                       MOD04106 INTRO273
      J=I+2                                                               MOD04107 INTRO274
C     TEST PRINT                                                                   INTRO275
      IF(II .NE. ITERAT) GO TO 223                                                 INTRO276
      WRITE(6,905) II,I                                                            INTRO277
 905  FORMAT(1H ,'FLOWS (Q) AND SOURCE-DIPOLE STRENGTHS (SM-SD) AT EACH            INTRO278
     * STA FOR ITERATION ',I1,                                       '             INTRO279
     1 FOR SHIP ',I1,/,5H NSTA,4X,3HQAP,8X        ,2HQY,8X,2HQZ,7X,                INTRO280
     2 3HUQA,7X,3HUQY,7X,3HUQZ,8X,2HSM,7X,3HSDY,7X,3HSDZ,7X,3HSUM,6X,              INTRO281
     3 4HSUDY,6X,4HSUDZ)                                                           INTRO282
  223 CONTINUE                                                                     INTRO283
      DO 230 L=1,NSTAI                                                    MOD04108 INTRO284
      IF(II .NE. ITERAT) GO TO 227                                                 INTRO285
      WRITE(6,910) L,QAP(I,L),        QY(I,L),QZ(I,L),UQA(I,L),UQY(I,L)            INTRO286
     1,UQZ(I,L),SM(I,L),SDY(I,L),SDZ(I,L),SUM(I,L),SUDY(I,L),SUDZ(I,L)             INTRO287
 910  FORMAT(1H ,I2,6(1X,F9.5),2(1X,F9.4,1X,F9.3,1X,F9.3))                          INTRO288
```

```
  227 CONTINUE                                                             INTRO289
C       END OF TEST PRINT                                                  INTRO290
        IF(II .EQ. ITERAT) GO TO 230                                       INTRO291
C       RESIZING SINGULARITIES FOR THE NEXT ITERATION                      INTRO292
        SM(I,L)=(UDIM(I)-OAP(I,L))*.5*RYZ(I,L)*DRYZDX(I,L)                 INTRO293
        SDY(I,L)=-QY(I,L)*.25*(1.+A22(I))*RY2(I,L)**2                      INTRO294
        SDZ(I,L)=-QZ(I,L)*.25*(1.+A33(I))*RZ3(I,L)**2                      INTRO295
        SM(J,L)=SM(I,L)                                           MOD04112 INTRO296
        SDY(J,L)=SDY(I,L)                                         MOD04113 INTRO297
        SDZ(J,L)=-SDZ(I,L)                                        MOD04114 INTRO298
C       RESIZING UNCORRECTED STATE SINGULARITIES                           INTRO299
        SUM(I,L)=(UDIM(I)-UOA(I,L))*.5*RYZ(I,L)*DRYZDX(I,L)                INTRO300
        SUDY(I,L)=-UQY(I,L)*.25*(1.+A22(I))*RY2(I,L)**2                    INTRO301
        SUDZ(I,L)=-UQZ(I,L)*.25*(1.+A33(I))*RZ3(I,L)**2                    INTRO302
        SUM(J,L)=SUM(I,L)                                         MOD04118 INTRO303
        SUDY(J,L)=SUDY(I,L)                                       MOD04119 INTRO304
        SUDZ(J,L)=-SUDZ(I,L)                                      MOD04120 INTRO305
  230 CONTINUE                                                    MOD04121 INTRO306
  240 CONTINUE                                                    MOD04122 INTRO307
  250 CONTINUE                                                    MOD04123 INTRO308
        DO 280 I=1,2                                              MOD04124 INTRO309
        NSTAI=NSTA(I)                                             MOD04125 INTRO310
C       TEST PRINT                                                TEST9999 INTRO311
        WRITE(6,900) I                                                     INTRO312
 900    FORMAT(1H ,'FLOW GRADIENTS (DQ) AND SOURCE-DIPOLE DERIVATIVES (-DT INTRO313
       1) AT EACH STA. FOR FOR SHIP ',I1,/,5H NSTA,2X,5HDQQADY,5X,5HDQQADZ,  INTRO314
       2 5X,5HDQQYDY,5X,5HDQQYDZ,5X,5HDQQZDZ,6X,4HSDYV,6X,4HSDYR,5X,5HDSMDT, INTRO315
       3 4X,6HDSDYDT,4X,6HDSDZDT,4X,6HDSYRDT,4X,6HDUQYDT)                  INTRO316
        DO 270 L=1,NSTAI                                          MOD04126 INTRO317
        SDYTOT=SDY(I,L)+SDYV(I,L)+SDYR(I,L)                       MOD04130 INTRO318
C       SDZTOT=SDZ(I,L)+SDZQ(I,L)+SDZW(I,L)                       MOD04131 INTRO319
        SDZTOT=SDZ(I,L)                                           MOD04131 INTRO320
C       DEFINE TIME DERIVATIVES FOR FLOW SINGULARITIES                     INTRO321
        DSMDT(I,L)=(SM(I,L)-OSM(I,L))*DELTI                       MOD04127 INTRO322
        DSDYDT(I,L)=(SDY(I,L)-OSDY(I,L))*DELTI                             INTRO323
        DSDZDT(I,L)=(SDZ(I,L)-OSDZ(I,L))*DELTI                             INTRO324
```

```
      DSYRDT(I,L)=(SDYR(I,L)-OSDYR(I,L))*DELTI                          INTR0325
C     DSZQDT(I,L)=(SDZQ(I,L)-OSDZQ(I,L))*DELTI                          INTR0326
      DUQYDT(I,L)=(UQY(I,L)-OUQY(I,L))*DELTI                   MOD04128 INTR0327
C     DUQZDT(I,L)=(UQZ(I,L)-OUQZ(I,L))*DELTI                   MOD04129 INTR0328
      WRITE(6,915) L,DQADY(I,L),DQADZ(I,L),DQYDY(I,L),DQYDZ(I,L),       INTR0329
     1 DQZDZ(I,L),SDYV(I,L),SDYR(I,L),DSMDT(I,L),DSDYDT(I,L),DSDZDT(I,L)INTR0330
     2 ,DSYRDT(I,L),DUQYDT(I,L)                                         INTR0331
  915 FORMAT(1H ,I2,5(1X,F9.6),7(1X,F9.4))                              INTR0332
C     END OF TEST PRINT                                                 INTR0333
C     CLACULATION OF FORCE COMPONENTS TO EACH STATION                   INTR0334
      FXSMDT(L)=PIRO4*DSMDT(I,L)~~*X1(I,L)~~                                INTR0335
      FX(L)=PIRO4*(QAP(I,L)*SM(I,L)+DQADY(I,L)*SDYTOT+DQADZ(I,L)*SDZTOT)MOD04132 INTR0336
     1 +FXSMDT(L)                                              MOD04133 INTR0337
      FYL=PIRO4*(QY(I,L)*SM(I,L)+DQYDY(I,L)*SDYTOT+DQYDZ(I,L)*SDZTOT)   MOD04134 INTR0338
      FYDYDT(L)=PIRO4*DSDYDT(I,L)                              MOD04135 INTR0339
      FY(L)=FYL+FYDYDT(L)                                      MOD04135 INTR0340
      FZL=PIRO4*(QZ(I,L)*SM(I,L)+DQYDZ(I,L)*SDYTOT+DQZDZ(I,L)*SDZTOT)*2.MOD04136 INTR0341
      FZ(L)=FZL+PIRO4*DSDZDT(I,L)*2.                           MOD04137 INTR0342
C     CALCULATION OF MOMENT COMPONENTS TO EACH STATION                  INTR0343
      RX(L)=PIRO4*(-QY(I,L)*SDZTOT+QZ(I,L)*SDYTOT)             MOD04138 INTR0344
C     RY(L)=-X1(I,L)*FZL+PIRO4*((QAP(I,L)-UDIM(I))*SDZ(I,L)+QAP(I,L)*   INTR0345
C    1 (SDZW(I,L)+SDZQ(I,L))+DUQZDT(I,L)*SDZQ(I,L)+UQZ(I,L)*DSZQDT(I,L))INTR0346
      RY(L)=-X1(I,L)*FZL+PIRO4*(QAP(I,L)-UDIM(I))*SDZ(I,L)              INTR0347
C     RZ(L)=X1(I,L)*FYL-PIRO4*((QAP(I,L)-UDIM(I))*SDY(I,L)+QAP(I,L)*    INTR0348
C    1 (SDYV(I,L)+SDYR(I,L))+DUQYDT(I,L)*SDYR(I,L)+UQY(I,L)*DSYRDT(I,L)7INTR0349
      RZQADY(L)=-PIRO4*(QAP(I,L)-UDIM(I))*SDY(I,L)                      INTR0350
      RZQAVR(L)=-PIRO4* QAP(I,L)*(SDYV(I,L)+SDYR(I,L))                  INTR0351
      RZDT(L)=-PIRO4*(DUQYDT(I,L)*SDYR(I,L)+UQY(I,L)*DSYRDT(I,L))       INTR0352
      RZ(L)=X1(I,L)*FYL+RZQADY(L)+RZQAVR(L)+RZDT(L)                     INTR0353
  270 CONTINUE                                                 MOD04146 INTR0354
C     NON-DIMENSIONALIZING FACTOR FOR FORCES                            INTR0355
      CND=FND(I)*UDIM(I)*UDIM(I)                                        INTR0356
C     NON-DIMENSIONALIZING FACTOR FOR MOMENTS                           INTR0357
      CNDR=CND*ALPP(I)                                                  INTR0358
      DXI=DX(I)                                                         INTR0359
C     SUMMED FORCE OVER SHIP'S LENGTH                                   INTR0360
                                                                    PAGE  28
```

```
      FXT(I)=SIMPSN(DXI,FX,NSTAI,M)/CND                              MOD04147 INTR0361
      FYT(I)=SIMPSN(DXI,FY,NSTAI,M)/CND                              MOD04148 INTR0362
      FZT(I)=SIMPSN(DXI,FZ,NSTAI,M)/CND                              MOD04149 INTR0363
      FXSMDT(I)=SIMPSN(DXI,FXSMDT,NSTAI,M)/CND                                INTR0364
      FYDYDT(I)=SIMPSN(DXI,FYDYDT,NSTAI,M)/CND                                INTR0365
C     SUMMED MOMENT OVER SHIP'S LENGTH                                        INTR0366
      RXT(I)=SIMPSN(DXI,RX,NSTAI,M)/CNDR                             MOD04150 INTR0367
      RYT(I)=SIMPSN(DXI,RY,NSTAI,M)/CNDR                             MOD04151 INTR0368
      RZT(I)=SIMPSN(DXI,RZ,NSTAI,M)/CNDR                             MOD04152 INTR0369
      RZQADY(I)=SIMPSN(DXI,RZQADY,NSTAI,M)/CNDR                               INTR0370
      RZQAVR(I)=SIMPSN(DXI,RZQAVR,NSTAI,M)/CNDR                               INTR0371
      RZDT(I)=SIMPSN(DXI,RZDT,NSTAI,M)/CNDR                                   INTR0372
      XINT(I)=FXT(I)*100000.                                                  INTR0373
      YINT(I)=FYT(I)*100000.                                                  INTR0374
      NINT(I)=RZT(I)*100000.                                                  INTR0375
C     OUTPUT FORCE AND MOMENT ON  SHIP                                        INTR0376
      WRITE(6,800) I,FXT(I),FYT(I),FZT(I),RXT(I),RYT(I),RZT(I)                INTR0377
     1 ,FXSMDT(I),FYDYDT(I),RZQADY(I),RZQAVR(I),RZDT(I)                       INTR0378
  280 CONTINUE                                                       MOD04153 INTR0379
      RETURN                                                                  INTR0380
  800 FORMAT('0    NON-DIMENSIONAL INTERACTION FORCES AND MOMENTS ON SHIP     INTR0381
     1 ',I1,  ' (MEASURED IN TERMS OF SHIP AXIS SYSTEM)',/,4X,                INTR0382
     2 11HSURGE FORCE,5X,10HSWAY FORCE,5X,10HSINK FORCE,4X,                   INTR0383
     3 11HROLL MOMENT,4X,11HTRIM MOMENT,5X,10HYAW MOMENT,/,6(5X,F10.7),       INTR0384
     4 /,4X,8HFXSMDT= ,F10.7,9H FYDYDT= ,F10.7,9H RZQADY= ,F10.7,             INTR0385
     5 9H RZQAVR= ,F10.7,7H RZDT= ,F10.7)                                     INTR0386
      END                                                                     INTR0387
```

```
      SUBROUTINE DIFEQ                                                          DIFQ0001
      REAL NDUU,NDU,NOU,NVU,NVVV,NVV,NV,NRVV,NDVV,NRV,NDV,NVRD,NRRR,NR, MODO2001 DIFQ0002
     1 NVRR,NDRR,NDDD,ND,NVDD,NRDD,NO,NVDOT,NRDOT,MT1,NBAR,NINT         MODO2001 DIFQ0003
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DINPRN,IPRNT,ITERAT        MODO2003 DIFQ0004
      COMMON/IN3DIM/ALPP(2),PMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),      MODO2005 DIFQ0005
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)                      MODO2005 DIFQ0006
      COMMON/IN7COF/XUUU(2),XUU(2),XU(2),XVV(2),XVR(2),XVD(2),          MODO2009 DIFQ0007
     2 XRR(2),XRD(2),XDD(2),XDDU(2),XO(2),XUDOT(2),                     MODO2009 DIFQ0008
     3 YDUU(2),YDU(2),YOU(2),YVU(2),YVVV(2),YVV(2),YV(2),YRVV(2),       MODO2009 DIFQ0009
     4 YDVV(2),YRV(2),YDV(2),YVRD(2),YRRR(2),YR(2),YVRR(2),YDRR(2),     MODO2009 DIFQ0010
     5 YDDD(2),YD(2),YVDD(2),YRDD(2),YO(2),YVDOT(2),YRDOT(2),           MODO2009 DIFQ0011
     6 NDUU(2),NDU(2),NOU(2),NVU(2),NVVV(2),NVV(2),NV(2),NRVV(2),       MODO2009 DIFQ0012
     7 NDVV(2),NRV(2),NDV(2),NVRD(2),NRRR(2),NR(2),NVRR(2),NDRR(2),     MODO2009 DIFQ0013
     8 NDDD(2),ND(2),NVDD(2),NRDD(2),NO(2),NVDOT(2),NRDOT(2)            MODO2009 DIFQ0014
      COMMON/IN9SPD/UO(2),CK5X(2),CK6U(2),CK7A(2),ULAG(2),UACC(2),      MODO2011 DIFQ0015
     1 UDEC(2),USENT(2)                                                 MODO2011 DIFQ0016
      COMMON/INOLOC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MODO2012 DIFQ0017
     1 YCONT,HEADER,UBREAK                                              MODO2012 DIFQ0018
      COMMON/OP1TIM/TIME,DELTI,SALPP(2),SDMLD(2),IST                    MODO3002 DIFQ0019
      COMMON/OP2CON/PI,PIRO4,DEGRAD,RADDEG,FND(2),FPSKTS                MODO3003 DIFQ0020
      COMMON/OP3DIM/X1(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21),         MODO3004 DIFQ0021
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4)         MODO3004 DIFQ0022
      COMMON/OP6FCR/XBAR(2),YBAR(2),NBAR(2),XINT(2),YINT(2),NINT(2),    MODO3007 DIFQ0023
     1 FXT(2),FYT(2),FZT(2),RXT(2),RYT(2),RZT(2)                        MODO3007 DIFQ0024
      COMMON/OP7ACC/UDDOT(2),UODOT(2),VDDOT(2),VODOT(2),RDDOT(2)        MODO3008 DIFQ0025
      COMMON/OP8RUD/DR(2),DRCAPT(2)                                     MODO3009 DIFQ0026
      COMMON/OP9SPD/UDIM(2),DELU(2),UODIM(2),V(2),VDIM(2),VODIM(2),R(2),MODO3010 DIFQ0027
     1 RDIM(2),UCAPT(2)                                                 MODO3010 DIFQ0028
C     CALCULATE TOTAL FORCES AND MOMENTS AT TIME                                 DIFQ0029
      DO 100 J=1,2                                                               DIFQ0030
      VAB=ABS(V(J))                                                     MODO2085 DIFQ0031
      RAB=ABS(R(J))                                                     MODO2086 DIFQ0032
      XBAR(J)=((XUUU(J)*DELU(J)+XUU(J))*DELU(J)+XU(J))*DELU(J)+(XVV(J)* MODO2087 DIFQ0033
     1 V(J)+XVR(J)*R(J)+XVD(J)*DR(J))*V(J)+(XRR(J)*R(J)+XRD(J)*DR(J))*  MODO2087 DIFQ0034
     2 R(J)+(XDD(J)*DR(J)+XDDU(J)*DR(J)*DELU(J))*DR(J)+XO(J)+XINT(J)    MODO2087 DIFQ0035
      YBAR(J)=((YDUU(J)*DELU(J)+YDU(J))*DR(J)+YOU(J)+YVU(J)*V(J))*      MODO2088 DIFQ0036
```

```
     1 DELU(J)+((YVVV(J)*V(J)+YRVV(J)*R(J)+YDVV(J)*DR(J))*V(J)+YVV(J)*  MODO2088 DIFQ0037
     2 VAB+YV(J)+YRV(J)*RAB+YVRD(J)*R(J)*DR(J))*V(J)+((YRRR(J)*R(J)+    MODO2088 DIFQ0038
     3 YVRR(J)*V(J)+YDRR(J)*DR(J))*R(J)+YR(J))*R(J)+((YDDD(J)*DR(J)+    MODO2088 DIFQ0039
     4 YVDD(J)*V(J)+YRDD(J)*R(J))*DR(J)+YD(J)+YDV(J)*VAB)*DR(J)+YO(J)+  MODO2088 DIFQ0040
     5 YINT(J)                                                          MODO2088 DIFQ0041
      NBAR(J)=((NDUU(J)*DELU(J)+NDU(J))*DR(J)+NOU(J)+NVU(J)*V(J))*      MODO2089 DIFQ0042
     1 DELU(J)+((NVVV(J)*V(J)+NRVV(J)*R(J)+NDVV(J)*DR(J))*V(J)+NVV(J)*  MODO2089 DIFQ0043
     2 VAB+NV(J)+NRV(J)*RAB+NVRD(J)*R(J)*DR(J))*V(J)+((NRRR(J)*R(J)+    MODO2089 DIFQ0044
     3 NVRR(J)*V(J)+NDRR(J)*DR(J))*R(J)+NR(J))*R(J)+((NDDD(J)*DR(J)+    MODO2089 DIFQ0045
     4 NVDD(J)*V(J)+NRDD(J)*R(J))*DR(J)+ND(J)+NDV(J)*VAB)*DR(J)+NO(J)+  MODO2089 DIFQ0046
     5 NINT(J)                                                          MODO2089 DIFQ0047
  100 CONTINUE                                                                   DIFQ0048
C     PRINT OUTPUT FOR TIME AND REVISE SPEED AND RUDDER CONTROL FOR TIME + DELT  DIFQ0049
      IF(TIME .NE. TIMPRN) GO TO 175                                             DIFQ0050
      CALL OUTPUT                                                                DIFQ0051
      TIMPRN=TIMPRN+DTNPRN*DELT                                                  DIFQ0052
  175 CONTINUE                                                                   DIFQ0053
      CALL CAPTN                                                                 DIFQ0054
C     CALCULATE ACCELERATIONS, VELOCITIES, DISTANCES, AND ANGLES FOR TIME + DELT DIFQ0055
      DO 200 J=1,2                                                               DIFQ0056
      UDDOT(J)=XBAR(J)*UDIM(J)*UDIM(J)/(XUDOT(J)*ALPP(J))                        DIFQ0057
      VDDOT(J)=(NRDOT(J)*YBAR(J)-YRDOT(J)*NBAR(J))*UDIM(J)*UDIM(J)/              DIFQ0058
     1 ((YVDOT(J)*NRDOT(J)-YRDOT(J)*NVDOT(J))*ALPP(J))                           DIFQ0059
      RDDOT(J)=(YVDOT(J)*NBAR(J)-NVDOT(J)*YBAR(J))*UDIM(J)*UDIM(J)/              DIFQ0060
     1 ((YVDOT(J)*NRDOT(J)-YRDOT(J)*NVDOT(J))*ALPP(J)**2)                        DIFQ0061
      DR(J)=DR(J)+DRCAPT(J)                                                      DIFQ0062
      UDIM(J)=UDIM(J)+UDDOT(J)*DELT+UCAPT(J)                                     DIFQ0063
      VDIM(J)=VDIM(J)+VDDOT(J)*DELT                                              DIFQ0064
      RDIM(J)=RDIM(J)+RDDOT(J)*DELT                                              DIFQ0065
      DELU(J)=(UDIM(J)-UO(J))/UDIM(J)                                            DIFQ0066
      V(J)=VDIM(J)/UDIM(J)                                                       DIFQ0067
      R(J)=RDIM(J)*ALPP(J)/UDIM(J)                                               DIFQ0068
      CI(J)=CI(J)+RDIM(J)*DELT                                                   DIFQ0069
      COSCI=COS(CI(J))                                                           DIFQ0070
      SINCI=SIN(CI(J))                                                           DIFQ0071
      UODOT(J)=UDDOT(J)*COSCI-VDDOT(J)*SINCI                                     DIFQ0072
```

```
      VODDT(J)=VODDT(J)*COSCI+UDDOT(J)*SINCI
      UODIM(J)=UDIM(J)*COSCI-VDIM(J)*SINCI
      VODIM(J)=VDIM(J)*COSCI+UDIM(J)*SINCI
      XDIM(J)=XDIM(J)+UODIM(J)*DELT
      YDIM(J)=YDIM(J)+VODIM(J)*DELT
      CND=FND(J)*UDIM(J)*UDIM(J)
      SINK(J)=FZT(J)*CND/TPI(J)
      TRIM(J)=RZT(J)*CND/MTI(J)
      ZDIM(J)=DEPTH-SINK(J)
      I=J+2
      XDIM(I)=XDIM(J)
      YDIM(I)=YDIM(J)
      ZDIM(I)=-ZDIM(J)
      CI(I)=CI(J)
      TRIM(I)=-TRIM(J)
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OUTPUT                                                          OUTP0001
      REAL NBAR,NINT,MT1                                                MOD03001 OUTP0002
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2),      MOD02005 OUTP0003
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)                      MOD02005 OUTP0004
      COMMON/INOLCC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MOD02012 OUTP0005
     1 YCONT,HEADBR,UBREAK                                              MOD02012 OUTP0006
      COMMON/OP1TIM/TIME,DELTI,SALPP(2),SBMLD(2),IST                    MOD03002 OUTP0007
      COMMON/OP2CON/PI,PIRO4,DEGRAD,RADDEG,FND(2),FPSKTS                MOD03003 OUTP0008
      COMMON/OP3DIM/XI(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21),         MOD03004 OUTP0009
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4)         MOD03004 OUTP0010
      COMMON/OP6FCR/XBAR(2),YBAR(2),NBAR(2),XINT(2),YINT(2),NINT(2),    MOD03007 OUTP0011
     1 FXT(2),FYT(2),FZT(2),RXT(2),RYT(2),RZT(2)                        MOD03007 OUTP0012
      COMMON/OP7ACC/UDDOT(2),UODOT(2),VDDOT(2),VODOT(2),RDDOT(2)        MOD03008 OUTP0013
      COMMON/OP8RUD/DR(2),DRCAPT(2)                                     MOD03009 OUTP0014
      COMMON/OP9SPD/UDIM(2),DELU(2),UCDIM(2),V(2),VDIM(2),VODIM(2),R(2),MOD03010 OUTP0015
     1 RDIM(2),UCAPT(2)                                                 MOD03010 OUTP0016
      WRITE(6,800)                                                               OUTP0017
      DO 100 J=1,2                                                               OUTP0018
      ACI=CI(J)*RADDEG                                                           OUTP0019
      VKNOTS=UDIM(J)*FPSKTS                                                      OUTP0020
      RU=DR(J)*RADDEG                                                            OUTP0021
      RDIMDG=RDIM(J)*RADDEG                                                      OUTP0022
      RDDOTD=RDDOT(J)*RADDEG                                                     OUTP0023
      TRIMD=TRIM(J)*ALPP(J)                                                      OUTP0024
      WRITE(6,900)   TIME,J,XDIM(J),YDIM(J),ACI , RU , VKNOTS,UDDOT(J),          OUTP0025
     1 VDIM(J),VDDOT(J),RDIMDG,RDDOTD,SINK(J),XBAR(J),YBAR(J),NBAR(J),           OUTP0026
     2 XINT(J),YINT(J),NINT(J),TRIMD                                             OUTP0027
  100 CONTINUE                                                                   OUTP0028
      RETURN                                                                     OUTP0029
  800 FORMAT(  '0TIME SHIP XPOSITION  YPOSITION     PSI       RUDDER             OUTP0030
     1VELOCITY   UDDOT         VDIM       VDDOT         RDIM      RDDOT          OUTP0031
     2 SINKAGE')                                                                 OUTP0032
  900 FORMAT(1X,F4.0,2X,I2,2(1X,F10.2),1X,F10.5,2(1X,F10.3),6(1X,F10.5)/         OUTP0033
     1 1X,6HXFOR= ,F10.4,7H YFOR= ,F10.4,6H MOM= ,F10.3,7H XINT= ,F10.4          OUTP0034
     2,7H YINT= ,F10.4,7H MINT= ,F10.4,12X,7H TRIM= ,F10.5,/)                    OUTP0035
      END                                                                        OUTP0036
```

```
      SUBROUTINE CAPTN                                                   CAPT0001
      REAL NBAR,NINT,MT1                                        MOD03001 CAPT0002
      COMMON/INITIM/DELT,BREAK,ENDTIM,TIMPRN,DTNPRN,IPRNT,ITERAT MOD02003 CAPT0003
      COMMON/IN3DIM/ALPP(2),BMLD(2),DISPL(2),CP(2),CM(2),DRAFT(2), MOD02005 CAPT0004
     2 A22(2),A33(2),TPI(2),MT1(2),XLCG(2),NSTA(4)              MOD02005 CAPT0005
      COMMON/INHRUD/DRMAX(2),DRDOT(2),DRSENT(2),CK1C(2),CK2R(2),CK3Y(2),MOD02010 CAPT0006
     1 CK4V(2),DLAG(2),DRO(2)                                   MOD02010 CAPT0007
      COMMON/IN9SPD/UO(2),CK5X(2),CK6U(2),CK7A(2),ULAG(2),UACC(2), MOD02011 CAPT0008
     1 UDEC(2),USENT(2)                                         MOD02011 CAPT0009
      COMMON/INOLCC/XDIM(4),YDIM(4),CI(4),PASDIS,XLDEC,DEPTH,ROW,IPASS, MOD02012 CAPT0010
     1 YCONT,HEADBR,UBREAK                                      MOD02012 CAPT0011
      COMMON/OP1TIM/TIME,DELTI,SALPP(2),SBMLD(2),IST            MOD03002 CAPT0012
      COMMON/OP2CON/PI,PIRD4,DEGRAD,RADDEG,FND(2),FPSKTS        MOD03003 CAPT0013
      COMMON/OP3DIM/X1(4,21),DX(4),ZDIM(4),RAD(2,21),RY2(2,21), MOD03004 CAPT0014
     1 RZ3(2,21),RYZ(2,21),DRYZDX(2,21),SIDE(2),SINK(2),TRIM(4) MOD03004 CAPT0015
      COMMON/OP7ACC/UDDOT(2),UODOT(2),VDDOT(2),VODOT(2),RDDOT(2) MOD03008 CAPT0016
      COMMON/OP8RUD/DR(2),DRCAPT(2)                             MOD03009 CAPT0017
      COMMON/OP9SPD/UDIM(2),DELU(2),UODIM(2),V(2),VDIM(2),VODIM(2),R(2),MOD03010 CAPT0018
     1 RDIM(2),UCAPT(2)                                         MOD03010 CAPT0019
      COMMON/OPOLCC/XREL(2),YREL(2),XCLEAR,HEAD(2),LX           MOD03011 CAPT0020
      DIMENSION DRC(4,2)                                                 CAPT0021
      WRITE(6,900)                                              MOD05002 CAPT0022
      LX=0                                                               CAPT0023
      DO 400 I=1,2                                              MOD05003 CAPT0024
      IF(ABS(XREL(2)) .GT. XCLEAR) GO TO 150                    MOD05004 CAPT0025
      LX=1                                                               CAPT0026
      IF(ABS(YREL(2)) .LT. YCONT) GO TO 200                     MOD05005 CAPT0027
  150 CONTINUE                                                  MOD05006 CAPT0028
C     SHIP IN COURSE KEEPING MODE OUTSIDE CONTROL ZONE          MOD05007 CAPT0029
      IF(TIME .GE. BREAK) HEAD(2)=HEADBR                        MOD05008 CAPT0030
      DRC(1,I)=CK1C(I)*(CI(I)-HEAD(I)-RDIM(I)*DLAG(I))          MOD05009 CAPT0031
      DRC(2,I)=CK2R(I)*(RDIM(I)-RDDOT(I)*DLAG(I))               MOD05009 CAPT0032
      DRCMMD=DRC(1,I)+DRC(2,I)                                  MOD05010 CAPT0033
      DRC(3,I)=0.0                                                       CAPT0034
      DRC(4,I)=0.0                                                       CAPT0035
          IF(TIME .GE. BREAK) GO TO 250
  160 CONTINUE                                                  MOD05011 CAPT0036
```

```
C     SHIP MAINTAINING INITIAL SPEED                                    MOD05012 CAPT0037
      UCMMD=CK6U(I)*(UO(I)-UDIM(I)+UDDOT(I)*ULAG(I))+                   MOD05013 CAPT0038
     1 CK7A(I)*(-UDDOT(I)*(DELT-ULAG(I))/DELT)                          MOD05014 CAPT0039
      GO TO 300                                                         MOD05015 CAPT0040
  200 CONTINUE                                                          MOD05016 CAPT0041
C     SHIP IN RELATIVE MOTION CONTROL MODE INSIDE CONTROL ZONE          MOD05017 CAPT0042
      J=3-I                                                             MOD05018 CAPT0043
      COSCI=COS(CI(J))                                                  MOD05019 CAPT0044
      SINCI=SIN(CI(J))                                                  MOD05020 CAPT0045
      VCOSCI=(VODIM(I)-VODIM(J))*COSCI                                  MOD05021 CAPT0046
      USINCI=(UODIM(I)-UODIM(J))*SINCI                                  MOD05022 CAPT0047
      DRC(1,I)=CK1C(I)*(2*CI(I)-HEAD(I)-CI(J)-(2.*RDIM(I)-RDIM(J))*DLAG(I))  MOD05023 CAPT0048
      DRC(2,I)=CK2R(I)*(2.*RDIM(I)-RDIM(J)-(2.*RDDOT(I)-RDDOT(J))*DLAG(I))  MOD05024 CAPT0049
      DRC(3,I)=CK3Y(I)*(YREL(I)+PASDIS*SIDE(I)-(VCOSCI-USINCI)*DLAG(I)))  MOD05025 CAPT0050
      DRC(4,I)=CK4V(I)*(VCOSCI-USINCI-((VODDT(I)-VODDT(J))*COSCI-       MOD05026 CAPT0051
     1 (UODDT(I)-UODDT(J))*SINCI)*DLAG(I))                              MOD05026 CAPT0052
      DRCMMD=DRC(1,I)+DRC(2,I)+DRC(3,I)+DRC(4,I)                        MOD05027 CAPT0053
C     SHIP I MAINTAINS ORIGINAL SPEED                                   MOD05028 CAPT0054
      IF(I .EQ. 1) GO TO 160                                            MOD05029 CAPT0055
      IF(IPASS .EQ. 1) GO TO 160                                        MOD05030 CAPT0056
      IF(XREL(2) .LT. -XLDEC) GO TO 160                                 MOD05031 CAPT0057
C     SHIP 2 MATCHES SPEED OF SHIP 1 AFTER -XLDEC                       MOD05032 CAPT0058
C     MAINTAIN POSITION ALONG SIDE SHIP 1 UNTIL BREAK TIME              MOD05041 CAPT0059
      IF(TIME .GE. BREAK) GO TO 250                                     MOD05042 CAPT0060
      UCMMD=CK5X(2)*(-XREL(2)+UODIM(2)*ULAG(2))+                        MOD05043 CAPT0061
     1 CK6U(2)*(UDIM(1)-UDIM(2)+UDDOT(2)*ULAG(2))+                      MOD05044 CAPT0062
     2 CK7A(2)*(-UDDOT(2)*(DELT-ULAG(2))/DELT)                          MOD05045 CAPT0063
      GO TO 300                                                         MOD05046 CAPT0064
  250 CONTINUE                                                          MOD05047 CAPT0065
      UCMMD=CK6U(2)*(UBREAK-UDIM(2)+UDDOT(2)*ULAG(2))+                  MOD05048 CAPT0066
     1 CK7A(2)*(-UDDOT(2)*(DELT-ULAG(2))/DELT)                          MOD05049 CAPT0067
  300 CONTINUE                                                          MOD05050 CAPT0068
C     CHECK COMMANDED RUDDER ANGLE AGAINST SENSITIVITY AND LIMITS       MOD05051 CAPT0069
      DRDIF=DRCMMD                                                      MOD05052 CAPT0070
      ADRDIF=ABS(DRDIF)                                                 MOD05053 CAPT0071
      IF(ADRDIF .LE. DRSENI(I)) GO TO 310                               MOD05055 CAPT0072
                                                                           PAGE   35
```

```
      RUD=DRDOT(I)*(DELT-DLAG(I))                                       MOD05056 CAPT0073
      IF(ADRDIF .GT. RUD) DRDIF=DRDIF*RUD/ADRDIF                         MOD05057 CAPT0074
      ADRDIF=ABS(DR(I)+DRDIF)                                           MOD05059 CAPT0075
      IF(ADRDIF .GT. DRMAX(I)) DRDIF=((DR(I)+DRDIF)*DRMAX(I)/ADRDIF)    MOD05060 CAPT0076
     1 -DR(I)                                                           MOD05061 CAPT0077
      GO TO 320                                                         MOD05062 CAPT0078
  310 CONTINUE                                                          MOD05063 CAPT0079
      DRDIF=0.0                                                         MOD05064 CAPT0080
  320 CONTINUE                                                          MOD05065 CAPT0081
      DRCAPT(I)=DRDIF                                                   MOD05065 CAPT0082
      RUD=DR(I)*RADDEG                                                  MOD05066 CAPT0083
      DRCMMD=DRCMMD*RADDEG                                              MOD05067 CAPT0084
      DRDIF=(DR(I)+DRDIF)*RADDEG                                        MOD05068 CAPT0085
      DO 325 J=1,4                                                               CAPT0086
  325 DRC(J,I)=DRC(J,I)*RADDEG                                                   CAPT0087
C     CHECK COMMANDED SPEED CHANGE AGAINST ACCELERATION LIMITS          MOD05069 CAPT0088
      U=UDIM(I)*FPSKTS                                                  MOD05070 CAPT0089
      IF(ABS(UCMMD) .LE. USENT(I)) GO TO 350                            MOD05070 CAPT0090
      ACMMD=UCMMD/(DELT-ULAG(I))                                        MOD05070 CAPT0091
      IF(ACMMD .LE. UACC(I)) GO TO 330                                  MOD05071 CAPT0092
      ACMMD=UACC(I)                                                     MOD05072 CAPT0093
      GO TO 340                                                         MOD05073 CAPT0094
  330 CONTINUE                                                          MOD05074 CAPT0095
      IF(ACMMD .LT. UDEC(I)) ACMMD=UDEC(I)                              MOD05075 CAPT0096
  340 CONTINUE                                                          MOD05076 CAPT0097
      UCAPT(I)=ACMMD*(DELT-ULAG(I))                                     MOD05078 CAPT0098
      GO TO 360                                                         MOD05079 CAPT0099
  350 CONTINUE                                                          MOD05080 CAPT0100
      UCAPT(I)=0.0                                                      MOD05081 CAPT0101
  360 CONTINUE                                                          MOD05082 CAPT0102
      UCMMD=UCMMD*FPSKTS                                                MOD05083 CAPT0103
      ACMMD=(UCAPT(I)+UDIM(I))*FPSKTS                                   MOD05084 CAPT0104
      WRITE(6,910) I,RUD,DRCMMD,DRDIF,U,UCMMD,ACMMD                     MOD05085 CAPT0105
  400 CONTINUE                                                          MOD05086 CAPT0106
      WRITE(6,920) DRC                                                           CAPT0107
      RETURN                                                                     CAPT0108
```

```
900 FORMAT( 99HO   SHIP   RUDDER   INIT ANG   COMMD CHG    ACT ANG   (DEG)  MOD05087 CAPT0109
   1 SPEED  INIT SPD  COMMD CHG   ACT SPD  (KTS))                            MOD05087 CAPT0110
910 FORMAT(5X,I1,9X,3(1X,F10.4),13X,3(1X,F10.4))                             MOD05088 CAPT0111
920 FORMAT(8H01 DRC= ,F10.3,6H DRR= ,F10.3,4H DRY= ,F10.3,6H DRV= ,         MOD05089 CAPT0112
   1 F10.3,9H  2 DRC= ,F10.3,6H DRR= ,F10.3,6H DRY= ,F10.3,6H DRV= ,         MOD05089 CAPT0113
   2 F10.3)                                                                  MOD05089 CAPT0114
    END                                                                               CAPT0115
```

```
      FUNCTION SIMPSN(DXE,Y,N,M)
      DIMENSION Y(21)
      SIMPSN=0.0
      N1=N-1
      DO 100 J=2,N1,2
  100 SIMPSN=SIMPSN+2.*Y(J)+Y(J+1)
      SIMPSN=DXE*(Y(1)-Y(N)+2.*SIMPSN)/3.
      RETURN
      END
```

```
//G.FT09F001 DD UNIT=TAPE9,LABEL=(1,NL),DISP=(NEW,PASS),
//     DCB=(DEN=2,RECFM=VS,LRECL=504,BLKSIZE=508)
//G.FT64F001 DD DSN=&&CALDATA,DISP=(NEW,PASS),UNIT=SCRATCH,SPACE=(22,1)
//G.SYSIN DD *,DCB=BLKSIZE=2000
```

```
NAVY OILER AO-177 SHIP 1, LARGE DESTROYER SHIP 2, REPLENISH AT 100 FT RUDDER STD DATA0001
   3.       240.      330.       .0        1.                        3          DATA0002
 500.         .16       .105     .0        5.        2.                         DATA0003
 560.6       88.      27400.     .61       .989     32.2                        DATA0004
    .93       .93       71.    2720.       .                  21                DATA0005
    .058      .137      .246     .378      .514      .651      .776      .866   DATA0006
    .937      .982     1.0       .987      .955      .906      .839      .741   DATA0007
    .622      .481      .320     .112      .007                                 DATA0008
    .0        .134      .295     .469      .627      .766      .871      .937   DATA0009
    .976      .995     1.0      1.0       1.0        .995      .982      .947   DATA0010
    .888      .797      .649     .422      .161                                 DATA0011
   1.0       1.0       1.0      1.0       1.0       1.0       1.0       1.0     DATA0012
   1.0       1.0       1.0      1.0       1.0       1.0       1.0       1.0     DATA0013
   1.0       1.0       1.0      1.0        .089                                 DATA0014
 -61.5       78.4    -209.2   -634.4    2046.7     133.8                        DATA0015
                     -165.5    308.2              1203.5                        DATA0016
           -515.7     -63.4                      -2566.8   -1604.6    4057.     DATA0017
                      176.7               552.8    -90.8                        DATA0018
-216.9      341.6                          24.4   2416.2      65.2              DATA0019
            261.5      21.                         156.3    -727.    -4820.     DATA0020
                                         -199.4   -241.5                        DATA0021
  92.      -159.5                          -8.1     32.8     140.3              DATA0022
  35.         3.0       1.0      4.       200.        .5      25.        .25    DATA0023
  -3.5                                                                          DATA0024
  15.          .00676   1.0      1.0        .5        .14       .18       .1    DATA0025
 529.        55.      7700.      .56       .8331    19.86                       DATA0026
    .93       .93       32.    1400.      6.19                21                DATA0027
    .011      .131      .220     .319      .435      .527      .634      .716   DATA0028
    .835      .934      .989    1.0        .993      .923      .789      .665   DATA0029
    .499      .400      .273     .176      .110                                 DATA0030
    .0056     .1237     .2415    .3600     .4754     .5906     .6990     .8004  DATA0031
    .8896     .9594     .9963   1.0        .9997     .9886     .9675     .9396  DATA0032
    .9055     .8681     .8286    .7850     .7350                                DATA0033
    .0737    1.0       1.0      1.0       1.0       1.0       1.0       1.0     DATA0034
   1.0       1.0       1.0      1.0       1.0       1.0       1.0       1.0     DATA0035
    .6108     .4946     .3777    .2610     .1440                                DATA0036
                                                                         PAGE  40
```

1.4	114.6	-155.2	-342.8	206.2	55.			DATA0037
.0	.0	-135.	168.6	.0	381.4			DATA0038
117.6	-40.8	.0	201.1	.0	-2625.6	-1055.1	.0	DATA0039
.0	-930.7	34.6	.0	-109.4	-230.8			DATA0040
-140.6	274.3				802.1	17.9		DATA0041
-15.2	58.7		-112.8		-318.2	-283.1		DATA0042
	-170.7	-45.5		-105.4	-280.3			DATA0043
9.1	-137.5				8.2	47.4		DATA0044
30.	5.	1.	14.	700.	1.75	87.5	.25	DATA0045
								DATA0046
17.	.00676	1.0	1.0	.5	.3	.18	.1	DATA0047
-550.	171.5	.0	100.	200.	300.	1.9905		DATA0048
200.	15.	20.						DATA0049

```
//  EXEC CALCOMP,OPTIONS='PAPER(10,WHITE),INK(BLACK,BP)'
```